DURABLE FIBER EXPOSURE ASSESSMENT

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EXECUTIVE SUMMARY

EPA is assessing the potential risks associated with the production and use of durable fibers and of products made from durable fibers. EPA is particularly concerned about the respirability of durable fibers which become airborne during processing. Durable fibers are those fibers which are slowly biodegraded or are non-biodegradable and can survive in biological systems for long periods of time; respirable fibers are those fibers with diameters less than 3.5 μm which can enter the small airways of the lower respiratory tract. EPA is investigating the potential for exposure to respirable fibers and the health effects associated with inhalation of a set of nine durable fibers to determine which fibers, if any, are a concern to human health and safety. The nine durable fibers under investigation are:

- Aramid fiber (Kevlar® and Nomex®);
- Attapulgite;
- Carbon/graphite fiber;
- Ceramic fiber;
- Erionite;
- Fiberglass (wool and textile);
- Mineral wool;
- Polyolefin; and
- Wollastonite.

Attapulgite, erionite, and wollastonite are naturally occurring mineral fibers.

In this study, the extent of exposure to airborne respirable and durable fibers during the processes of fiber production, fiber product manufacture, and fiber product use is assessed. This study focuses on those fiber applications which are likely to generate the highest levels of airborne respirable fiber. Engineering and monitoring results (data from NIOSH site visits, academic studies, process simulations, and industry members) for each fiber are summarized below. This summary ends with conclusions identifying those fibers and fiber products which appear to have the greatest potential for generation of high concentrations of airborne respirable fibers given the available monitoring data.

A. Aramid Fibers

There are two types of aramid products, Kevlar® and Nomex®, which are both produced solely by DuPont. A total of 500 employees work on the aramid fiber production lines year-round. Pulp manufacture, which accounts for approximately 10 percent of aramid fiber production, is contracted out to another company.

1. Kevlar®

Kevlar® is available in dry pulp (2 mm or 4 mm average lengths), wet lap (wet pulp sold in sheets containing 55 percent water), short fiber (1/4-1/2 inch long), staple fiber (1.5-4 inches long), and continuous filament forms. The core Kevlar® fiber has a nominal diameter of 12 μm; however, abrasion such as during the manufacture of pulp forms fine submicron (<1 μm in diameter) fibrils which remain attached to the core fiber. There is some potential for the submicron fibrils to break off and become airborne.

a. Kevlar® Production

Most Kevlar® fiber and pulp process steps are automated and do not involve direct contact by many workers. The major points for potential fiber exposure are packaging of dry pulp, staple, and short fibers; cutting of staple and short fiber; and fluffing of dry pulp. Airborne fiber concentrations are <0.06 fibers/cc for spinning and yarn handling, and only as high as 0.3 fiber/cc for pulp making and 0.44 fiber/cc for fiber cutting. Fiber concentrations ranged to below the detection limit of 0.01 fiber/cc for all operations.

b. Kevlar® Use

The forms of Kevlar® fiber which are likely to generate the highest levels of airborne fiber during use are the pulp (dry and wet) and short fiber forms.

(1) Friction Materials

Dry pulp is used in the "dry-mix" manufacture of friction materials such as automobile disc brake pads, truck brake blocks, and industrial friction materials. A total of 11 companies make friction products from dry Kevlar® pulp using a dry mix process. This process has a high potential for airborne fiber generation because the fiber remains in a dry state until it is cured, and drilling and grinding are likely to generate dust. The degree of automation in this industry is highly variable. In general, vacuum dust capturing systems are used over each process step. The number of workers on a line is highly variable, ranging from 2-3 operators to 70-80 operators, depending on level of production. Brake block production is typically a full-time operation (3 shifts/day); disc brake pad production is intermittent (e.g., 2 days/week). Airborne fiber concentration ranges from 0.01-0.07 fibers/cc; maximum likely time-weighted average (TWA) exposure is 1 fiber/cc.

Friction products such as drum brake linings, railroad brakes, and clutch facings are generally manufactured using a "wet-mix" process. A total of 5 companies make friction products from dry Kevlar® pulp using a wet-mix process. The degree of automation in this industry is highly variable as was the case for the "dry-mix" friction products. In general, vacuum dust capturing systems are used over each process step. One producer indicated that only 2-3 operators are in contact with the Kevlar® while it is in a dry state; as many as 100 employees could be involved in the entire operation. Monitoring data are not available, but it is expected that the fiber introduction, dry mixing, and finishing steps are the likely locations of potential exposure.

(2) Compressed Sheet Gaskets

Compressed sheet gaskets are also manufactured using dry Kevlar® pulp in a wet-mix process; Garlock and Victor Products are the only producers identified. No controls for airborne fiber emissions are used by this industry. Operations are full-time, and three operators (fiber feeder, finished product remover, and control room operator) are required to run the line. Average airborne fiber concentrations are 0.05 fibers/cc, with maximum exposures as high as 0.09 fibers/cc. The expected 8-hour TWA is <0.1 fibers/cc.

(3) Friction Papers

Wet-lap Kevlar® pulp is used in the manufacture of off-highway friction materials, automatic transmission paper, and gasket paper. Four manufacturers produce these friction papers. A papermaking line requires 10-11 operators: one to unload wet-lap rolls (unopened), two to add raw materials in the pulping area, 6 to run the papermaking line, and 1-2 to package the product. Engineering controls are not used since the pulp is always in a wet form.

Staple and continuous filament applications include textiles and belts for radial tires. These applications are expected to generate lower levels of airborne fiber emissions than the uses described above.

2. Nomex®

Nomex® is available in continuous filament, staple fiber, and paper forms. Short fibers are only manufactured internally for papermaking. Nomex® fiber has a nominal diameter of 12 µm; it does not have the tendency to form fine fibrils when abraded as Kevlar® does.

Fiber and papermaking processes are continuous and automated. Airborne fiber monitoring in the fiber production and finishing areas yielded readings below the detection limit (0.01 fiber/cc). Cutting and packaging of staple fibers are the operations most likely to generate airborne fibers.

Uses of Nomex® are less likely to generate airborne fiber emissions than Kevlar® pulp applications.

B. Attapulgite

Attapulgite is manufactured in absorbent (coarse) and gellant (fine) grades. Five companies mine and mill attapulgite.

1. Attapulgite Mining and Milling

Earthmoving equipment is used to remove the overburden at the mine; the wet clay can then be mined and manually loaded on trucks. The milling process is enclosed and equipped with vacuum dust collection systems and bag houses; however, significant quantities of dust are still generated during milling, screening, and bagging operations. Attapulgite is transferred automatically to each process step. Operators wear dust masks, and maintenance workers wear respirators. The number of employees in direct contact with the clay ranges from as low as 40-45 people to as high as 300-320 people. In the mill, respirable dust levels (0.16-3.24 mg/m^3) are generally below the OSHA/MSHA limits of 5 mg/m^3 for respirable nuisance dust. However, total dust levels (0.46-22.5 mg/m^3) exceed the OSHA and MSHA limits of 15 mg/m^3 and 10 mg/m^3, respectively. Fiber analysis indicates that more fibers are in the dust from the dryers and Raymond mills (fine grinding machinery) than in other areas. All fibers identified were of respirable size (median diameter equals 0.07 μm).

2. Attapulgite Use

The use of attapulgite for pet litter, oil and grease absorbents, and fertilizer/pesticide carriers was investigated.

a. Oil and Grease Absorbents/Pet Litter

Little, if any, further processing of the milled attapulgite is required for these applications. Attapulgite producers may package the milled clay for these applications or sell it in bulk to repackagers who perform the same operations. Dust control systems are used near the storage tanks and packaging machines. Two to three people work on a packaging line and wear dust masks. Each plant has 2-3 packaging lines. Potential exposure is covered in the milling discussion above.

b. Agricultural Carriers

Attapulgite is used as a carrier for pesticides, herbicides, etc. The process is completely automated and enclosed (including the bagging step) because of the toxicity of the pesticide being sprayed onto the clay. Two to three operators work on a line and are often inside control rooms to prevent exposures to pesticides. When in the operating area, workers may wear dust masks. Vacuum dust collection systems and baghouses are used to remove dust from the work area.

C. Carbon/Graphite Fibers

Carbon fibers are manufactured year-round by 10 companies at 22 plants; Hercules, Union Carbide, and Celanese/BASF are the largest manufacturers. Nominal carbon fiber diameters range from 5 to 8+ μm.

1. Carbon Fiber Manufacture

Carbon fiber is manufactured by the carbonization of precursor fibers such as polyacrylonitrile (PAN, most common), rayon, and pitch. Wind-up, chopping, and packaging operations are most likely to generate airborne fibers. Because of the high tensile strength of the carbon fibers, they are extremely fragile. Carbon fiber manufacture is highly automated, enclosed, and ventilated. The fiber chopping machine is enclosed, and negative pressure suction draws the fibers into containers. Carbon fibers are sometimes milled to 200 μm in length for specialty conductive applications. Carbon fiber manufacturers employ as few as 10 employees to as many as 250 employees; however, the percentage of these employees in direct contact with the carbon fibers in unknown. In general, workers are not located in areas of exposure at all times. Airborne fiber concentrations during carbon fiber manufacture range from 0.011 to 0.27 fibers/cc.

2. Carbon Fiber Use

By far the largest use of continuous and chopped carbon fibers is for composite materials and reinforced plastics. In the production of pre-pregs, carbon fibers arranged as tows or fabrics are impregnated with a matrix in a bath, or are sandwiched between two layers of matrix. Many of the primary carbon fiber manufacturers also manufacture pre-pregs. The pre-preg operation is largely automated and locally exhausted. Once the fibers are impregnated, there is little potential of airborne emissions. In reinforced plastic production, potential exposures can occur during fiber introduction, mixing, and product finishing. Exposures are also likely during grinding and cutting of molded parts. Local exhaust, vacuum systems, and water sprays help to minimize fly during grinding and cutting.

D. Ceramic Fibers

There are two types of refractory ceramic fibers: non-continuous and continuous.

1. Non-Continuous Ceramic Fibers

Refractory ceramic fibers range from 1 to 4 microns in nominal diameter (actual diameters range from 0.1-10 μm).

a. Refractory Ceramic Fiber Production

Five companies manufacture refractory ceramic fibers nearly year-round (300-320 days/year). Refractory ceramic fibers are sold in bulk and blanket forms. The bulk fiber is used as a loose fill or packaging in expansion joints, furnace crown cavities, and wall cavities, or to make felt, board, and paper. The process for producing refractory blanket is highly automated and enclosed, and dust collection systems are used throughout. Three to six laborers may work on a line. One person operates both the furnace and the fiber attenuation steps; this worker remains in an isolated control room. Since raw materials weighing and mixing is automated, an operator is not required, but up to 2 workers may be employed at this step. One operator can run 3 needlers, and 1 to 2 workers package the bulk fiber and the blankets. Dust masks or other respiratory protection are only required when airborne fiber concentrations exceed 2 fibers/cc. In general, airborne fiber concentrations are <1 fiber/cc; the highest exposure point was 2.5 fibers/cc for an unidentified plant location. The slitter/cutter/packager and the furnace operator (who also watches over the fiber attenuation process) are exposed to the highest fiber concentrations. Ninety percent of the airborne fibers are respirable.

b. <u>Refractory Ceramic Fiber Use</u>

The applications investigated were paper, board, and felt production; fabrication; and installation of furnace refractory.

(1) <u>Paper, Board, and Felt Production</u>

Bulk ceramic fiber is used to make paper, board, and felt products on conventional papermaking equipment. There are five major manufacturers of ceramic paper and board products. Ceramic fiber for papermaking processes is 1.5-6 microns in diameter and 1.5-12 inches in length. The papermaking process is automated except for fiber introduction and packaging of finished rolls. Local ventilation is used in these facilities. Monitoring data were provided for two facilities. One facility showed exposures <0.5 fibers/cc (0.1 fiber/cc average); the second facility showed exposures as high as 3.4 fibers/cc (1.1 fibers/cc average).

Vacuum formed shapes are also made by a process which is similar to papermaking. All of the refractory ceramic fiber producers plus an unknown number of independent contractors manufacture vacuum formed shapes. Exposures are very high during vacuum forming; fiber concentrations range from 0.12 to 23 fibers/cc (4.3 fibers/cc average).

(2) <u>Ceramic Product Fabrication</u>

Ceramic fiber products are finished in fabrication shops where 4 to 25 laborers manually cut and finish ceramic blankets, vacuum formed shapes, and other products to specification using saws, mechanical shears, sanders, and sewing machines. The level of ventilation varies in these shops;

some shops are only generally ventilated while others use exhaust fans with dust collectors. Respirators are used in fabrication shops. Exposures to airborne fibers are all <1 fiber/cc during both blanket fabrication and vacuum form finishing. Eighty-eight to 100 percent of the airborne fibers generated are respirable.

(3) Installation and Removal of Ceramic Refractory Products

Between 50 and 75 insulation contractors in the U.S. use ceramic insulation materials. Each contractor may employ 25 to 200 people; however, only about 10 percent of these workers handle ceramics, and only 5 percent of their time per year is spent working with ceramics. There are two basic methods for installing furnace insulation, both of which are manual operations: the wallpaper method (ceramic blanket is held up by anchors on the furnace wall) and the modular veneering method (prefabricated pieces installed using refractory mortar). Subsequent removal of wallpaper type insulation is easy because the installation process is simply reversed; modular veneering insulation, however, must be manually ripped-off the furnace wall creating a higher potential for exposure. Ceramic refractory is installed in industrial settings where controls of some sort already exist; some contractors use their own portable controls such as fans to improve ventilation. The Thermal Insulation Manufacturers Association (TIMA) performed worst case simulation studies of various insulation installation and removal operations; the estimated fiber concentration levels range from 4.1 to 9.5 fibers/cc, and almost 100 percent of the airborne fibers are respirable (mean diameter ranges from 0.7 to 1.4 μm).

2. Continuous Ceramic Fibers

Continuous ceramic fibers, having nominal diameters ranging from 11 to 20 μm, are produced by 3M and DuPont (pilot plant). The production process for textile fibers is almost fully automated and enclosed. Five to 6 employees operate a line during each 8-hour shift: one furnace operator who oversees up to 10 furnaces, one spinneret operator, and 3 to 4 roamers who perform maintenance and packaging duties. Packaging is the dustiest operation; local exhaust systems and dust masks help to minimize exposures. Exposure to airborne fiber during textile fiber production is extremely low (0-0.0005 fiber/cc), and the airborne fibers are not respirable (diameters range from 9.3 to 37 μm). Use of ceramic textile fibers is not likely to be a concern with respect to respirable fiber exposures.

E. Erionite

Erionite is a natural zeolite which is not currently mined or used. Erionite fibers range from 0.02 to 3 μm in diameter (depending on the location of the deposit) and from 10 to 20 μm in length.

1. Erionite Production

Erionite may exist as a trace contaminant in other natural zeolites such as chabazite produced by Union Carbide. Mining and milling of erionite is likely to be similar to mining and milling of other natural zeolites.

Between 6 and 14 miners are needed to remove the ore from the bed, and mining is generally intermittent. Dust controls are generally not used until the Raymond milling step because the zeolite is not completely dry until this point; Raymond mills are enclosed and are under negative pressure. Packaging machines are automated; the bagger operator need only load the machine with empty bags and remove the full bags. Erionite milling is generally automated and enclosed; about 7 operators are required for milling operations. All employees including maintenance personnel wear MSHA rated dust masks. Total and respirable dust levels in a chabazite/ erionite mine are below OSHA limits of 15 mg/m^3 and 5 mg/m^3, respectively. Only 0.4 to 33 percent of the total dust is respirable. Few fibers were found in these airborne dust levels because chabazite (the main component of the ore) is not fibrous.

2. Erionite Use

Erionite has been used or has the potential to be used as a molecular sieve, a hydrocracking catalyst, or a wastewater treatment ion exchange material. However, erionite is currently not used at all because other natural and synthetic zeolites perform better than erionite.

Potential exposures for other zeolites used in these applications were investigated; but at this time, there are no potential exposures to erionite.

F. Fiberglass

There are two types of fiberglass: fiberglass wool and textile fiberglass. Textile fiberglass generates less respirable airborne fiber because it is continuous or chopped in relatively long strands (compared to wool products), it has larger nominal diameters and narrower diameter distributions than the wool forms, and the manufacturing process is highly automated. Nominal fiber diameters for standard wool insulation products range from 1.5 to 15 µm; fine fibers (~1 µm in diameter) and microfibers (<1 µm in diameter) are manufactured for specialty applications.

1. Fiberglass Production

Five companies manufacture fiberglass wool at a total of 26 facilities. Many products can be made on the same fiberglass wool production line, ranging from blowing wool (often produced by milling recycled scrap) to blanket forms of insulation. Local ventilation is used in the fiber forming, curing, and cooling areas of the process; dust collection equipment is used by about half of the facilities to control fiber release to the atmosphere from these exhaust systems. The spinning and binding steps do not require ventilation because they are under negative pressure. Workers are not exposed to the fiberglass until the blanket cutting step because the process is highly automated. Cutting, trimming, and packaging areas are equipped with vacuum exhaust and dust collection equipment (e.g., baghouses). Respirators are worn by maintenance workers while cleaning dust collection filters and cure ovens.

Continuous textile fiberglass is made by 7 companies at 14 facilities. The major point of exposure during textile fiberglass production is during wind-up operations.

The available monitoring data for fiber production processes indicate that airborne fiber concentrations for standard wool and textile products are comparable and are ≤0.2 fiber/cc. Exposures are highest during fabrication, cutting, scrap reclamation, and packaging where workers are in close contact with the fiberglass product. The data also indicate that the nominal diameter of the fiberglass product has a significant effect on airborne fiber concentrations and respirability of airborne fibers. Mean airborne fiber concentrations observed during the production of microfibers (i.e., fibers with diameters <1 μm) range from 1 to 21.9 fibers/cc. Airborne fibers generated from microfiber production are 100 percent respirable, compared to approximately 70 to 80 percent (ranging from 35 to 93 percent) for standard insulation production.

2. Fiberglass Wool Use

This study focuses on applications for fiberglass wool because there is more potential for airborne fiber generation during downstream use of these products than there is for textile fiberglass applications. Particular attention is paid to paper and filtration products, and aircraft insulation because they use fine fibers (~1 μm in diameter) or microfibers (<1 μm in diameter). Exposures during installation of insulation products are also assessed because these operations are very labor intensive.

a. Paper and Filtration Products

Paper and filtration products are made with fiberglass microfibers. Conventional papermaking processes are used to manufacture these products. The major points of exposure are during fiberglass introduction to the pulper and during fabrication (e.g., cutting) of filters and other products. Local ventilation is used in the batch (e.g., pulper) and manual operation areas. Transfer of fiberglass paper scrap to the pulper for recovery is enclosed and ventilated. Eight to ten workers are required to operate a papermaking line. Airborne fiber concentrations are high for paper manufacturing operations using fiberglass microfibers; concentrations as high as 6 fibers/cc are not unusual. One study indicated fiber concentrations ranging from 10.6 to 44.1 fibers/cc; other studies indicated that mean exposure might be about 3 fibers/cc. The beaterman is exposed to the highest levels of airborne fibers. The percentage of airborne fibers which are respirable ranges from 72 to approximately 100 percent.

b. <u>Aircraft Insulation</u>

Aircraft insulation is made with fine fiberglass (~1 μm in diameter). Manufacture of aircraft insulation involves the manual fabrication (e.g., operation of cutting and sewing machines) of fiberglass mat to make irregular shapes. There are generally less than 100 people at a facility. Local ventilation may be used by some facilities. The metallized cover over the fiberglass mat reduces the potential for exposure during installation. The majority of available exposure data indicates that workers are generally exposed to <1.5 fibers/cc, except in the mat cutting and quilting machine operations where exposures as high as 4 fibers/cc were experienced. Between 90 and 100 percent of the airborne fibers are respirable.

c. <u>Installation of Insulation Materials</u>

Installation of insulation materials is a manual operation. This discussion focuses on the two most common forms of insulation materials, blankets and blowing wool. Workers are only exposed for about half their workday; the rest of the day is spent in transit from jobsite to jobsite, on breaks to avoid heat exhaustion, and switching from high to low exposure operations. In addition, installers will occasionally work with materials other than fiberglass. For the installation of blowing wool, 2 to 3 workers are required; one worker opens the bags of blowing wool and empties them into the blowing machine (located outside the building), and the other worker (the "blower") holds the hose and directs its spray. Local ventilation using engineering controls cannot be applied at a jobsite; jobsite ventilation is achieved by opening windows and doors. Airborne fiber exposure levels are very dependent upon the level of ventilation. Exposures are high for blowing wool installers because these materials are usually sprayed into attics which are poorly ventilated.

Exposure data for installation of blowing wool and of blanket insulation in attics indicate that blowing wool installation generates more airborne fiber. The blower operator is exposed to an average fiber concentration of 1.8 fibers/cc and point exposures as high as 4.8 fibers/cc; 44 percent of this airborne fiber is respirable. The blanket installer is exposed to average concentrations of 0.1 to 1.02 fibers/cc with point exposures as high as 1.8 fibers/cc; 80 to 90 percent of this airborne fiber is respirable.

G. Mineral Wool

Mineral wool is a man-made fiber produced from slag (most commonly) or rock. The nominal fiber diameter for mineral wool products ranges from 6 to 9 μm; Fiberfine produces 3 to 5 μm diameter mineral wool.

1. Mineral Wool Production

Nine companies at 16 plants manufacture mineral wool. Total plant employment ranges from 29 to 250 workers; only 70 to 80 percent are potentially exposed to mineral wool. Blowing wool is the most common mineral wool product, followed by batts.

The spinning and fiberization steps and the dedusting oil treatment are enclosed operations. The production of mineral wool is highly automated; only the jobs at the cupola area and packaging area are labor intensive. The blowing wool bagging machine is automatic and uses hydraulic injection; the bagging operator simply loads empty bags and removes filled bags. Mineral wool batts are manually stacked into bagging machines by take-off table workers. Local ventilation, possibly leading to a baghouse fiber collection system, is usually present at the bagging operations and sometimes at the cupola. Six to 9 workers are needed to operate a blowing wool production line; 10 to 13 workers are needed to operate a batt production line.

In general, airborne fiber concentrations are <1 fiber/cc for all process operations, and approximately 50 to 60 percent of the airborne fibers are respirable. The cupola, take-off table, and bagger operators are exposed to the highest levels of airborne fibers, as high as 2.6 fibers/cc for one facility.

2. Mineral Wool Use

This study investigated both installation of insulation materials and of fireproofing materials.

a. Installation of Insulation Materials

Installation of insulation materials is a manual operation. There are approximately 200 insulation contractors in the U.S., and most operate at more than one location. Insulation contractors handle a variety of insulation materials; the workload is distributed by fiber type as follows: 80 percent fiberglass, 10 percent mineral wool, and 10 percent other materials including ceramics. The installation operations for mineral wool blowing wool and batts are the same as those described above for fiberglass.

In installation of blowing wool, the blower operator is exposed to the highest concentrations of airborne fibers; average concentrations for the blower operator range from 0.6 to 4.2 fibers/cc, and total concentrations range from 0.2 to 20 fibers/cc. The other one or two workers who are outside the building are exposed to much lower fiber concentrations, 0.035 to 1.4 fibers/cc average and as high as 4.4 fibers/cc for one job monitored.

The same contractors who install mineral wool installation may also be involved in removal operations. A study of three men removing old insulation and replacing it with new material indicated that exposures during removal are much higher than for installation. The average respirable fiber TWA for removal is 2 fibers/cc (60-70 percent of fibers are respirable), and the corresponding TWA for installation is 0.5 fiber/cc.

b. Installation of Fireproofing

Installation of fireproofing material is performed by plasterers. A crew might perform a fireproofing task once a month. Two to three installers are needed to blow fireproofing material onto steel, or roof decking; the procedure is very similar to that used for blowing wool installation, except that the fibers are mixed with water as they leave the nozzle. The plasterer ("blower") spends 70 to 80 percent of the installation time close to the area being coated, and he often gets coated by the material also. The plasterer wears a hood, helmet, and glasses, but he does not wear a respirator because it tends to fog up due to the high moisture levels present. As with other installation operations, engineering controls for ventilation cannot be used. Exposure data show no difference in exposure for the plasterer or the assistant who loads the hopper; airborne fiber concentrations range from 0.4 to 0.65 fibers/cc.

H. Polyolefin Fibers

Polyolefin fibers are produced from polypropylene and polyethylene. Ninety-five percent of U.S. polyolefin fiber is produced from polypropylene.

1. Polyolefin Fiber Production

There are 87 polyolefin fiber manufacturers in the the U.S. operating 113 plants. Seven forms of polyolefin fiber are marketed, these are monofilament yarn (≥153.8 μm diameter), multifilament yarn (5-20 μm diameter), staple fiber (chopped multifilament, 1-8 in. long), tape and fibrillated film yarn (continuous sheet, not a fiber), spun-bonded fabric, synthetic pulp (5-40 μm diameter, 2.5-3 mm length), and microfiber (1-5 μm diameter, 2 μm diameter average). Polyolefin fiber production processes are generally automated and often enclosed. Only general ventilation is used in the polyolefin fiber production plants, and only cleaning workers wear dust masks. For all the processes listed above, packaging, wind-up (fiber breakage), and cutting operations are most likely to generate airborne fibers. Depending on the type of cutting machinery being used, the cutting operation may be enclosed to control noise levels. Total dust levels are far below OSHA's limit for nuisance dust.

2. Polyolefin Fiber Use

This study focuses on the applications of the synthetic pulp, microfiber, and staple fiber forms of polyolefin fiber because these forms have the finest diameters and are likely, therefore, to generate the highest levels of airborne respirable fibers.

a. Pulp Uses

Polyolefin synthetic pulp (Pulpex®) applications can be classified into paper products and non-paper products. Synthetic pulp is available in dry fluff and wet-lap (sheet) forms.

Paper and felt products are made on conventional automated papermaking machines. Eight to ten operators run a line. Raw materials handling, cutting, and finishing operations are the dustiest operations; and ventilation is used to control exposure to dust and fibers. The wet-lap form of Pulpex®, which contains 50 percent water and pulp with diameters ranging from 10-40 μm for polyethylene and 20-40 μm for polypropylene, is used to make paper and felt products. There is little potential for fiber emissions once the fiber is encapsulated in the paper.

The dry fluff form of Pulpex®, having diameters ranging from 6-15 μm for polyolefin and 5-10 μm for polypropylene, is used in non-paper applications. Bags of pulp are manually opened and emptied into a mixing vessel where the pulp is blended with wet ingredients and packaged. The product is pumped directly to drums; the packaging operator simply places lids on the drums. This process is enclosed except for the fiber introduction and product packaging steps. Exposure to fibers during packaging is limited because the fiber is encapsulated. Operators at the fiber introduction area have the highest potential for fiber exposure; therefore, they wear dust masks. There is also local ventilation over the mixing vessel. Two to 4 workers are required on the production line.

b. <u>Microfiber Uses</u>

Thinsulate® is a polyolefin microfiber produced by 3M for use as thermal insulation for clothing and other applications. Spinning, carding, and rolling (of the finished product) are likely exposure points. Companies buy these batts and manually cut and sew them into desired products. These secondary operations are very labor intensive, and ventilation and protective equipment are generally not used.

c. <u>Staple Fiber Uses</u>

Phillips Fibers and Hercules are the largest staple fiber producers. Rope, made on automated rope-making equipment, is the major application for polyolefin staple fibers. Fiber introduction and combing operations are the likely exposure points.

I. Wollastonite

Wollastonite is a naturally occurring mineral fiber. The average diameter of wollastonite is 3.5 μm (1 to 10 μm range), and milled products have aspect ratios ranging from 3:1 to 20:1, depending on the grade. Wollastonite particles break up easily because of their low tensile strength, and particles with aspect ratios of 1:1 are possible.

1. Wollastonite Mining and Milling

Three companies produce wollastonite. NYCO is the only producer of high aspect ratio wollastonite for plastic reinforcement. Mines and mills may operate 8 hours/day year-round or intermittently.

Wollastonite can be mined in one of three ways depending on the thickness of the overburden: open pit mining, surface mining (similar to open pit mining, but little or no overburden is present), and underground mining. Engineering controls are not appropriate for mining operations. Dust masks are used during open pit mining, and cartridge respirators are used in underground mining (especially during drilling). Mining requires 3 workers for small operations and about 15 for large operations, including truckers.

The ore is transferred to a mill where the ore size is reduced, and rocks and impurities are removed. Local ventilation systems along with dust collection systems are commonly used through wollastonite mills near machine operations which are dusty. Dusty operations include bagging, milling (which may be enclosed), drying, and transfer conveyors and elevators. Transfer conveyors are commonly enclosed and exhausted; closed pneumatic transfer is also used. Dust masks or positive pressure respirators with filters and full face mask are used by mill operators. Five to 20 operators are needed to mill wollastonite during each shift, depending on the production volume and the number of grades being produced.

Total and respirable dust exposures during mining and milling of wollastonite are generally below the OSHA nuisance dust limits of 5 mg/m^3 and 15 mg/m^3 for respirable and total dust, respectively. Total dust exposures for the miller, packer, flotation operator, and maintenance worker approach or exceed the OSHA limit. During mining operations, total airborne fiber concentration is approximately 5 fibers/cc (<1 fiber/cc were ≥5 μm in length). Milling operations generate extremely high airborne fiber concentrations for the beneficiator, miller, and packer; total fiber concentrations range from 33 to 85 fibers/cc (31 to 65 fiber/cc were ≥5 μm in length). Median airborne fiber size is 0.22 μm in diameter and 2.5 μm in length; 92 to 97 percent of the total airborne fibers are respirable.

2. Wollastonite Use

This study focuses on the use of wollastonite in ceramics and coatings because these applications consume the largest quantities of wollastonite.

a. Ceramics

200-325 Mesh wollastonite is used in ceramic tile products. There are two techniques used in this industry for manufacturing tile: (1) the fiber may be mixed with liquid to form a soft mud which is extruded into tile, or (2) the fiber can be dry-mixed with clay and other dry ingredients and pressed into a mold. Mixers are generally closed. Tile production operators commonly wear dust masks. Ventilation is often used at the fiber introduction, dry-mixing, tile pressing, and glaze spraying operations which are dusty. Five to 7 workers are needed per shift to operate a tile manufacturing line; plants may operate 1 to 3 shifts/day.

b. Coatings

200 to 325 Mesh wollastonite is used in paint and coating products. Wollastonite is used in traditional liquid coatings but also in powder coatings; occupational exposure during manufacture of powder coatings will be much higher than for liquid coatings. In the production of liquid coatings, dust collection systems are used over to open tub of the mixer, and the fiber loader wears a dust mask.

Solid coatings are first dry mixed, followed by melt mixing which encapsulates the fiber. The melt mix is chill rolled and then ground to a fine powder (20-30 μm in diameter). Vacuum dust collection systems are used in all work areas, and operators wear dust masks.

J. Conclusion

Based on the data presented in this study, several generalizations can be made about the potential for exposure during fiber production and use. Exposures during man-made fiber production are typically low (<1 fiber/cc) because processes are highly automated and/or enclosed such that operators are rarely in direct contact with the fiber. Even many of the packaging operations are automated and ventilated, and the exhaust is sent to dust collection equipment. Production of fine fibers or microfibers, however, yields much more airborne fiber and a higher percentage of respirable fibers even with the use of engineering controls; exposures on the order of 10 fiber/cc and higher have been experienced during these operations for fiberglass. Personal protective equipment is rarely used.

Production of naturally occurring fibers presents a totally different exposure scenario since the fiber is present from the beginning of the production process. Mining operations are labor intensive and exposures are likely; however, most mining is performed in open pits which allows for some ventilation. Although milling operations use mechanical grinding and screening machines, workers are required to run these machines. Milling operations are extremely dusty, and both dust and fiber concentrations have been shown to exceed OSHA's nuisance dust standards significantly. During wollastonite milling, fiber concentrations ranging from 30 to 80 fibers/cc are not uncommon. Respirators and dust masks are used more often in the production of natural fibers than in the production of man-made fibers.

This study focused on the fiber uses which appeared to have the greatest potential for respirable fiber emissions. Microfiber, fine fiber, and pulp were of top priority due to their small nominal diameters. In general, higher exposures are experienced during downstream use of a fiber than during the production of a fiber. Fiber introduction (which is often manual), dry mixing, cutting and sewing, and grinding and finishing operations are typical points of high exposure. Exposure data for the production of filtration products using microfiber fiberglass indicated exposures of 10 to 44 fibers/cc, with highest exposure levels being experienced by the beaterman who loads fiber into the beater.

Some uses, such as installation of insulation materials, involve highly manual operations in locations where engineering controls cannot be applied and natural ventilation is limited. Installation of blowing wool is a prime example of such an operation. The blower operator is exposed to as much as 20 fibers/cc in some instances, although his average exposure is much lower. Approximately 40 percent of the airborne fibers during blowing wool installation are respirable.

The data contained in this study indicate that there are several processes and operations which generate significant quantitites of respirable airborne fiber concentrations. There are also processes and operations which generate very little airborne fiber because of automation, enclosure, or ventilation. In general, microfiber and fine fiber production and use, production and use of some of the naturally occurring mineral fibers which make use of dusty milling and screening processes, and operations which involve manual handling of the fibers are of major concern with respect to durable fiber exposures. In addition, it is likely that a good percentage (50 to 100 percent, depending on fiber and process) of the airborne fibers are respirable.

Table ES-1 presents a summary of the fibers and corresponding processes/operations which appear to generate the highest concentrations of airborne respirable fibers based on the results of this study and are, therefore, of most concern with respect to occupational exposure.

Table ES-1. Fibers and Fiber Applications With the Greatest Potential for Generating High Concentrations of Airborne Respirable Fibers

Fiber	Process/Operation	Exposure Levels	Percent of Fibers that are Respirable
Attapulgite	Milling (Screening, Bagging)	Respirable Dust: 0.16-3.24 mg/m^3 Total Dust: 0.46-22.5 mg/m^3 (Mostly particulate, not fibers)	NK
Ceramic	Production of Vacuum Formed Shapes	0.12-23 fibers/cc (Average: 4.3 fibers/cc)	NK
	Paper and Board Production	As high as 3.4 fibers/cc (Average: 1.1 fibers/cc)	NK
	Installation of Furnace Insulation	4.1-9.5 fibers/cc (Worst case simulation)	100%
Fiberglass	Production of Microfibers (<1 um diameter)	1-21.9 fibers/cc	100%
	Production of Paper and Filtration Products Using Microfibers	10.6-44.1 fibers/cc (6 fibers/cc is not unusual)	70%-100%
	Production of Aircraft Insulation Using Fine Fibers (<1 um diameter)	4 fibers/cc for cutting and quilting (<1.5 fibers/cc generally)	90%-100%
	Installation of Blowing Wool Insulation	1.8-4.8 fibers/cc (Short term)	44%
Mineral Wool	Blowing Wool Production	As high as 2.6 fibers/cc for the cupola, take-off table, and bagger operators (<1 fiber/cc generally)	50%-60%
	Blowing Wool Installation (and Removal)	0.6-4.2 fibers/cc (Range of averages) 0.2-20 fibers/cc (Range of all samples)	NK
Wollastonite	Mining	5 fibers/cc (<1 fiber/cc longer than 5 um)	NK
	Milling	33-85 fibers/cc (31-65 fibers/cc longer than 5 um) for miller and packager	92%-97%

NK = Not known.

I. INTRODUCTION/METHODOLOGY

EPA is assessing the potential risks associated with the production and use of durable fibers and of products made from durable fibers. EPA is particularly concerned about the respirability of durable fibers which become airborne during processing. Durable fibers are those fibers which are slowly biodegraded or are non-biodegradable and can survive in biological systems for long periods of time; respirable fibers are those fibers with diameters less than 3.5 microns which can enter the small airways of the lower respiratory tract. EPA is investigating the potential for exposure to respirable fibers and the health effects associated with inhalation of a set of nine durable fibers to determine which fibers, if any, are a concern to human health and safety. The nine durable fibers under investigation are:

- Aramid fiber (Kevlar® and Nomex®);
- Attapulgite;
- Carbon/graphite fiber;
- Ceramic fiber;
- Erionite;
- Fiberglass (wool and textile);
- Mineral wool;
- Polyolefin; and
- Wollastonite.

Attapulgite, erionite, and wollastonite are naturally occurring mineral fibers.

The purpose of this preliminary survey is to seek information about the extent of exposure to airborne respirable and durable fibers during the processes of fiber production, fiber product manufacture, and fiber product use. Our approach consists of four steps as follows:

- Identify fiber producers, uses, users, and fiber sizes produced;

- Seek information about manufacturing processes, focusing on the potential for durable fiber emission;

- Seek data on the number of employees exposed to airborne durable fibers and the duration of exposure; and

- Identify available monitoring data that quantify exposure and/or fiber size distributions of airborne fiber emissions.

Our methodology is presented below.

A. Methodology

ICF has recently prepared a set of "Industry Market Profiles" for the nine durable fibers under investigation. These profiles served as our reference for identifying producers and uses of the fibers. The major uses of the durable fibers are presented in Table 1.

Our approach to assessing exposure to durable fibers involved searching for information about manufacturing processes and emission controls, size distribution of fibers emitted, and occupational exposure. Our first step was to identify the available exposure data in the literature. We performed a literature search using the NIOSH, NTIS, MEDLINE, and Chemical Industry Notes on-line databases. In addition, we performed a search of all Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) publications related to fiber exposure using the OSHA Technical Data Center's on-line system. NIOSH reports included "Hazard Evaluation and Technical Assistance Reports (HHEs)," "Industry Wide Study Reports (IWs)," "Control Technology Reports (CTs or Walk-Through Survey Reports)," and "Contractor Reports." We also obtained all available Toxic Substances Control Act (TSCA) Section 8(e) and "FYI" industry submissions from EPA. Exposure data and fiber size distributions for fiberglass and mineral wool production operations and insulation installation operations were reasonably abundant. Exposure data, although limited, were available for all the other fibers except polyolefins. Most data available in the literature are for fiber manufacture; however, we were able to gather some useful information on exposure for a few of the fiber uses investigated.

Table 1. Major Uses and Market Shares for Selected Durable Fibers

Fiber	Major Uses and Market Shares
Aramid	
a. Kevlar®	Radial Tire Cords (40%) Protective Clothing (20%) Plastic Reinforcements and Composites (20-30%) Ropes and Cables (5%)
b. Nomex®	Electrical Insulation (50%) Hot Gas Filters and Protective Clothing (50%) Composites, Ironing Board Covers
Attapulgite	Pet Litter (35%) Oil and Grease Absorbents (30%) Drilling Mud (10%) Pesticides (9%) Fertilizer (5%) Other (11%)
Carbon/Graphite	Aerospace (68%) Sporting Goods (17%) Industrial (14%) Plastics Reinforcement High Temperature Insulation
Ceramic	Packing Aerospace Applications and Paper Production Furnace and Kiln Linings and Backup Insulation Foundry Components Heat Shields Expansion Joints
Erionite	Cement and Concrete Additive Paper Filler
Fiberglass	
a. Wool	Structural Insulation (84%) Industrial Equipment Insulation (13%) Pipe Insulation (2%) Other (1%)
b. Textile	Reinforced Plastics and Composites (56%) Roof Shingles and Miscellaneous (38%) Paper and Tape (3%) Tires (2%) Home Furnishings (1%)

Table 1 (Continued)

Fiber	Major Uses and Market Shares
Mineral Wool	Structural Insulation Industrial Equipment Insulation Additive to Cement, Mortar, and Ceiling Tile
Polyolefin	Carpets and Rugs (49%) Home Furnishings and Bags (22%) Rope and Cordage (11%) Staple Nonwovens (12%) Other (6%)
Wollastonite	Ceramic Additive (50%) Paint Additive (25%) Plastics and Rubber Reinforcement, Abrasives, and Insulation Products (25%)

To supplement the literature, we contacted industry sources for information on fiber handling, process automation and emission controls, fiber sizes, number of exposed employees, duration of exposure, and protective equipment. Several of these companies were able to provide fiber monitoring results for their facilities or to recommend trade associations, contacts in academia, or conference proceedings which contained the desired information from process simulations or site visits.

The monitoring results were compared to available OSHA and Mining Safety and Health Association (MSHA) standards and guidelines to determine if the exposures were significant. Specific OSHA standards (Permissible Exposure Limits, PELs) have been set for nuisance dust; these PELs are legally enforceable. Many companies use the Threshold Limit Values, TLVs, recommended by the American Conference of Governmental Industrial Hygienists as internal guidelines. TLVs are available for a greater number of fibers than are the PELs, and TLVs are often more stringent than the corresponding PELs for some fibers. The PELs and TLVs applicable to this study are presented below.

- Nuisance Particulates (alumina, calcium silicate, cellulose, graphite, mineral wool fiber, silicon, silicon carbide, etc.) -- containing <1 percent quartz

  PEL: 5 mg/m^3 or 15 mppcf (respirable dust) (also MSHA limit)
  15 mg/m^3 or 50 mppcf (total dust)
  (mppcf = million particles per cubic foot of air; mppcf x 35.3 = particles/cc)

  TLV: 5 mg/m^3 (respirable dust)
  10 mg/m^3 or 30 mppcf (total dust)

- Mineral Wool Fiber, Fibrous Glass, and Graphite (Synthetic)

  TLV: 10 mg/m^3 (total dust)

Based on information provided by fiber producers on the form (continuous, chopped, pulp, microfiber, etc.) and nominal diameters of their fibers used in the various applications presented in Table 1, we were able to focus on those applications which appeared most likely to generate airborne fibers of respirable size. In general, microfiber and pulp applications took top priority, followed by short fibers, staple fibers, and continuous fibers. The uses discussed in this report are:

- Aramid: friction materials, sheet gasketing, and friction papers made from Kevlar® pulp;
- Attapulgite: oil and grease absorbents/pet litter, and agricultural chemical carriers;
- Carbon/Graphite: composite materials, reinforced plastics, and felt for furnace insulation;
- Ceramics: installation of refractory furnace insulation, and paper;
- Erionite: molecular sieves, catalysts, and wastewater treatment ion exchange;
- Fiberglass: paper and filtration products made from microfibers, aircraft insulation made from fine fibers (~1 μm in diameter), and installation of insulation materials;
- Mineral Wool: installation of insulation materials;
- Polyolefin: paper products and non-paper products made from pulp, batts and clothing made from microfibers, rope-making using staple fibers; and
- Wollastonite: ceramics and coatings.

By investigating the applications with the highest potential for exposure first, estimates of the importance of other fiber applications with respect to fiber exposure can be made.

B. <u>Report Organization</u>

There is a chapter devoted to the discussion of each fiber. Potential for exposure during fiber production is discussed first, followed by potential for exposure during fiber use. Within each subsection (e.g., for production, for uses), producers or manufacturers are identified; processes/operations and the level of automation, enclosure, emission control, and protective equipment usage are assessed; and extent of potential exposure including number of workers exposed, duration of exposure, and fiber concentrations and size distributions is discussed. Each chapter includes a list of references. Summaries of this information are included in the Executive Summary. A glossary is appended to define key technical terms used throughout this report.

II. ARAMID FIBER

Aramid fiber is defined by the U.S. Federal Trade Commission as a manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which at least 85 percent of the amide (-CO-NH-) linkages are attached directly to two aromatic rings (Preston 1978). There are currently two types of aramid fibers in production in the United States, Nomex® and Kevlar®, both made by E.I. duPont de Nemours & Company (hereafter referred to as DuPont). Kevlar® and Nomex® fibers both have diameters of approximately 12 microns (Merriman and Norman 1981; DuPont 1986b). Kevlar® has long, strong, axial, crystalline "grains" separated by weaker amorphous regions; abrasion of Kevlar® fiber produces many very fine fibrils or subfibers on the surface of the core fiber. The fibrils are curled, flattened, and branched, rather than straight. They have diameters of less than one micron; their length to diameter ratio is often over 500 (Merriman and Norman 1981). Some fibrils may split off from the core fiber; these would probably be the fibers of concern when looking at possible fiber exposures. Nomex®, on the other hand, has a different type of structure and does not form fibrils, according to a DuPont representative. Nomex® is more like conventional nylons (which are also polyamide fibers) than Kevlar® in this regard (DuPont 1986a).

Both Kevlar® and Nomex® are resistant to heat, flame, and most chemicals, and are good electrical insulators. The major difference between the two aramids is the superior strength of Kevlar®. Nomex® is comparable in strength to other synthetic fibers such as nylon and polyester, while Kevlar® is approximately twice as strong (Preston 1978). An additional difference is the tendency of Kevlar to form fibrils, as discussed above. Fibrillation improves the mixing behavior of Kevlar® fibers. The reinforcing properties of Kevlar® are also improved by fibrillation because of the high length to diameter ratio of the fibrils (Merriman and Norman 1981). Both Kevlar® and Nomex® are used for their heat and flame resistance (e.g., in some types of protective clothing), but only Kevlar® is used where high strength is required (e.g., in ballistics protection and in high-performance composites). Only Kevlar®, in the form of fibrillated pulp, is used for asbestos replacement in friction materials and gaskets.

Available information on production processes for aramids and possible fiber emissions is discussed below. DuPont has provided monitoring data on Kevlar® and Nomex® production. DuPont considers data on processes, automation, and number of people exposed to be proprietary; therefore, little specific information was available in these areas. General information on synthetic fiber production is discussed when no specific information on aramids was found.

Kevlar® and Nomex® are discussed separately below because, although they are chemically similar, there are significant differences in their properties and uses.

A. Kevlar®

1. Fiber Production

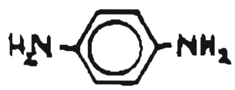
a. Fiber Producers

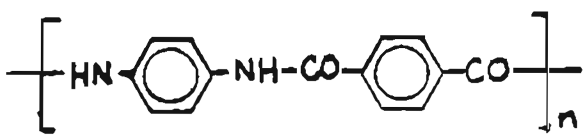
Kevlar® fibers are produced by DuPont at the Spruance Fiber Plant in Richmond, Virginia. Kevlar® has been produced at this location since its commercial introduction in 1970 (Chemical Week 1983, Preston 1978). Total employment at this plant is 3,500 (Dun and Bradstreet 1986); Nomex® fibers, fluorocarbon fibers, hollow fibers, and fiber optics are also produced at this location. There are 500 production employees for aramid fibers, both Kevlar® and Nomex® combined (DuPont 1986e).

Production capacity for Kevlar® is 45 million pounds per year. Capacity was tripled from 15 million pounds to 45 million pounds in 1983, and future expansion to 70 million pounds is planned (Chemical Week 1983). Sales of Kevlar® were reported by one source to be 25 million pounds in 1985 (Chemical Week 1986); another source estimated a total of 24 million pounds, with 19 million pounds sold in the United States (OMNIA 1986).

b. Fiber Production Process/Potential Exposure Points

(1) Process Description and Automation

Kevlar® is produced by the polymerization of p-phenylenediamine () and terephthaloyl chloride () to yield poly(p-phenyleneterephthalamide), which has the following structure:



Polymerization is carried out in solution; the polymerization process is shown in Figure 1.

Filament Formation. The processing of Kevlar® fiber is shown in Figure 2. The polymer is spun out of a sulfuric acid solution into a filament, using a wet-spinning process. The polymer solution is extruded through spinnerets at a temperature of 51-100°C (124-212°F). The extruded filaments are passed through a layer of air (0.5-1.9 cm) into a cold water bath at a temperature of 0-4°C (32-39°F). The filaments are washed thoroughly with water and dried on bobbins (Chiao and Chiao 1982).

The washing step in synthetic fiber production can occur either continuously or in batches (USEPA 1982). According to a DuPont

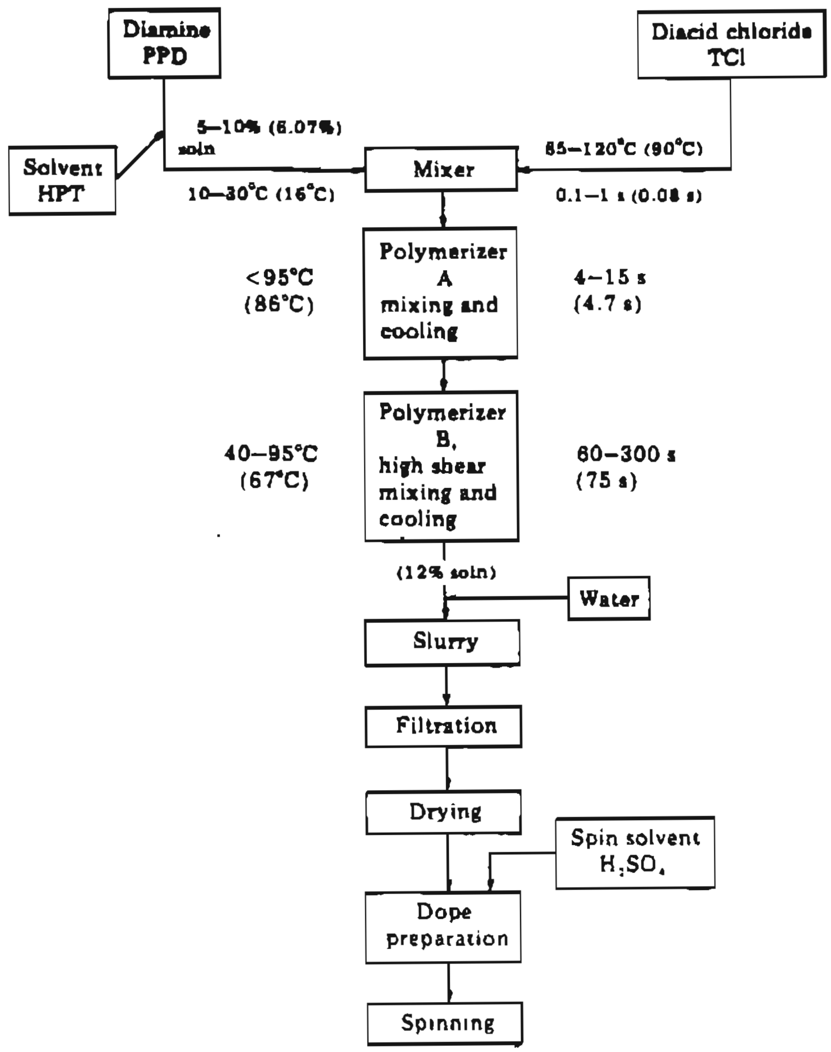


Figure 1. Preparation of Kevlar®. (NOTE: Values in parentheses are from an actual example in U.S. Pat. 3,850,888 (November 26, 1974).) (Source: Preston 1978, p. 234.)

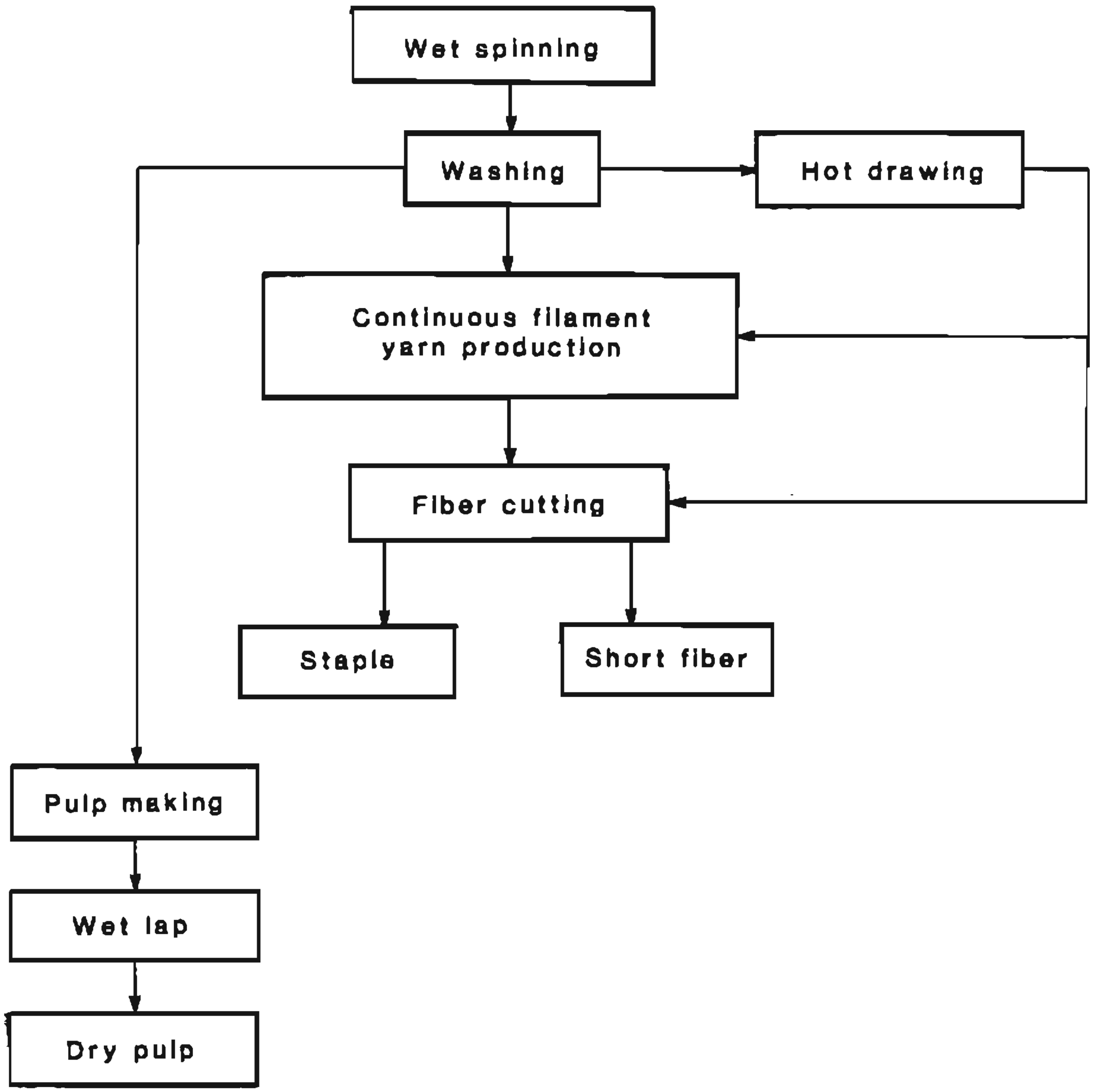


Figure 2. Kevlar® fiber processing. (Source: ICF, based on DuPont 1985, Preston 1978, Rebenfeld 1983, and USEPA 1982.)

representative, most Kevlar® production processes are continuous (DuPont 1986a). A lubricant is often applied to wet-spun synthetic fibers following the washing step (USEPA 1982).

Kevlar®-49, the highest-modulus type of Kevlar®, is further treated by hot drawing; other forms of Kevlar® are probably not hot drawn (Preston 1978). Drawing involves stretching the yarn to introduce molecular orientation, producing a stronger fiber. Drawing of fibers is carried out by stretching them between two or more rollers. One roller feeds the yarn; the next roller, which rotates at a greater speed, collects the yarn and feeds it to another roller or subsequent processing (USEPA 1982).

Other operations carried out after spinning probably include yarn production from the continuous filaments and winding of the yarn for shipment. Yarn is produced from continuous filament by twisting groups of filaments together slightly or by grouping filaments together without twisting.

DuPont's monitoring results (discussed in Section c below) show testing, rewinding, and unspecified yarn handling operations as manufacturing operations carried out after spinning (DuPont 1985). It appears that yarn testing may be a separate operation carried out in a laboratory, and not part of the manufacturing processes. The monitoring results do not describe any of the operations, and DuPont would provide no details.

Other operations carried out during the manufacturing process include cutting the continuous filament into staple (1-1/2 to 4 inches or 38 to 100 millimeters in length) and short fibers (1/4 inch (6 millimeters) or 1/2 inch (13 millimeters) long) (DuPont (n.d.)a). No details about the cutting procedures used were available.

<u>Pulp Formation</u>. DuPont also sells Kevlar® in the form of a pulp. Pulp production is a contractor operation (the name of the contractor

was not available) carried on outside DuPont. According to a DuPont representative, pulp is produced by a process of abrasion, yielding fibers with many attached fibrils; the details of this process were not available. The pulp is initially produced as a wet lap (a coarse paper containing 55 percent water), so it is probable that the abrasion process is carried out in water, which would likely serve to minimize fiber emissions. The pulp is sold either as rolls of wet lap or as dry pulp. The dry pulp is produced by drying, shredding, and fluffing the wet lap. Dry pulp is packaged in 10-pound bags (DuPont 1985a). No information was available on the production and packaging of dry pulp. Pulp is produced in two lengths, 1/2 to 8 millimeters, averaging 4 millimeters, or 1/2 to 4 millimeters, averaging about 2 millimeters. Pulp fiber core diameter is 12 microns; however, the attached fibrils may be less than 1 micron in diameter (Merriman and Norman 1981).

Although DuPont did not supply any process information, a DuPont representative stated that most of the processes used in Kevlar® production are continuous and do not involve contact by many workers (DuPont 1986a), indicating that there may be a high level of automation.

(2) Engineering Controls and Protective Equipment

No specific information was available about engineering controls and protective equipment used during Kevlar® production. A DuPont representative stated that there are probably no controls used specifically for fiber or dust because levels are too low for concern. Controls (unspecified) might be used in some areas because of the presence of solvents or other chemicals (DuPont 1986a). It seems likely that controls would be used during polymer production and spinning of the fiber, for example.

c. Extent of Potential Exposure

DuPont has provided monitoring information on fiber concentrations during Kevlar® production. There are 500 production employees for aramid fibers (both Nomex® and Kevlar® combined); this would be the maximum number of people potentially exposed to the fibers during production (DuPont 1986e). Production is carried out 365 days per year (DuPont 1986c). Although DuPont considers the number of shifts per day to be proprietary (DuPont 1986a), it seems likely that there are three shifts per day.

DuPont has provided job titles and descriptions for Kevlar® production workers as follows (DuPont 1986e):

- Auxiliary Operator, Spinneret Lab -- Disassembles, cleans, inspects, and reassembles spinnerets; operates ultrasonic cleaner and "Freon" dryer.
- Production Machine Operator, Spinning -- Operates spinning machine, handles solution and waste yarn, takes samples, changes filters.
- Production Testing Operator -- Performs routine physical testing on yarn, to include deniering, textile testing, spooling, and finish on yarn testing.
- Miscellaneous Operator -- Miscellaneous assignments, transporting yarn to finishing.
- Finishing Operator -- Operates finishing equipment and winders, and releases packed production.
- Nylon Finishing Operator -- Operates beamers.

DuPont did not provide information on the number of employees in each job classification.

DuPont's monitoring results for polymer spinning, yarn testing, yarn rewinding, and yarn handling operations, and the job titles of personnel involved in these operations are shown in Table 1. Monitoring for all DuPont operations presented here (Tables 1-3) was done using procedures described in NIOSH Analytical Method P & CAM 239. Full-shift fixed area samples were

Table 1. DuPont's Monitoring Results for Kevlar® Manufacturing Operations

Exposed Personnel	Location	Process	Samples	Count Range (Fibrils/cc)
Production Machine Operator	Plant 2	Polymer spinning	4	N.D.[a]
Production Machine Operator	Plant 3	Polymer spinning	5	N.D. - 0.01
Production Testing Operator	P.T. Lab	Yarn testing	2	N.D.
Nylon Finishing Operator	Beaming	Yarn rewinding	4	N.D.
Finishing Operator	Processing	Yarn handling 1	5	N.D. - 0.01
Finishing Operator	Processing	Yarn handling 2	4	N.D. - 0.06
Finishing Operator	Processing	Yarn handling 3	3	N.D. - 0.01

[a] N.D. (Not Detected) is below the limit of detection, 0.01 fibers/cc.

NOTE: Results are for full shift (8 hour) fixed area samples. Standard procedures were used for collection and fiber analysis, as described in NIOSH Analytical Method P & CAM 239. Samples were analyzed using phase contrast optical microscopy.

Source: DuPont 1985, Attachment III.

collected using membrane filters and a sampling pump (DuPont 1986e). Samples were analyzed using phase contrast optical microscopy. A piece of the filter is mounted, and the filter is dissolved. The number of fibers in the microscope field is then counted. This procedure is repeated up to 100 times (Analytics, Inc. 1986). Fiber concentrations ranged from below the limit of detection (0.01 fibers/cc) to 0.06 fibers/cc.

There is a greater potential for fiber exposure during fiber cutting than during the fiber spinning and yarn handling operations. None of the job descriptions provided by DuPont, however, refer to fiber cutting operations. DuPont's monitoring results for fiber cutting operations, shown in Table 2, indicate that fiber concentrations during cutting operations are somewhat higher than for fiber spinning and yarn handling. Fiber concentrations measured ranged from 0.01 to 0.44 fibers/cc. According to DuPont, this range may include both area and personal samples; the results are not reported by sample type. Area monitoring was carried out under the most stringent conditions possible; that is, samples were collected in the areas likely to have the highest fiber concentrations, although for only a short period of time (e.g., when bags are loaded or unloaded). According to a DuPont representative, there would usually be no human exposure at these levels because these operations are highly automated and area samples may be taken where there are no workers (DuPont 1986a). Operation B, 20-50 minute monitoring results, in Table 2 might be an area sample based on the short sampling time and the relatively high fiber concentration. Personal samples were taken over longer periods of time for workers in all job classifications (DuPont 1986a).

According to DuPont, pulp production is the process most likely to result in fiber emissions (DuPont 1986a). As mentioned earlier, fibrils of diameter

Table 2. DuPont's Monitoring Results for Kevlar®
Fiber Cutting Operations

Operation	Date	Sampling Time	Number of Samples	Maximum Count (fibers/cc)	Range, Excluding Maximum (fibers/cc)
A[a]	1983	6 hours	4	0.44	0.2-0.33
B[b]	1985	3-4 hours	7	0.04	0.01-0.03
		20-50 minutes	5	0.44	0.02-0.08
C[b]	1985	3-6 hours	10	0.05	0.01-0.02
D[b]	1985	2-5 hours	8	0.02	0.01

[a] Operation is no longer used; all others are still in use.

[b] Preliminary data.

NOTES: NIOSH 7400 and P & CAM 239 methods were used. Samples were analyzed by phase contrast optical microscopy. Results may include both area and personal monitoring (DuPont 1986a); Operation B, 20-50 minutes, may be area monitoring.

Source: DuPont 1985, Attachment IV.

less than 1 micron may be produced by abrasion, as in pulp-making. Monitoring data for pulp-making operations are shown in Table 3. Fiber concentrations measured range from 0.02 fibers/cc to a maximum of 0.3 fibers/cc. Both area and personal monitoring may be included in these results. Operation E, 80 minutes (maximum count 0.3 fibers/cc), may be an example of area monitoring.

OMNIA, a consulting firm for the advanced composites industry, estimates that 2.4 million pounds of aramid fibers (presumably Kevlar®) were used in brakes and gaskets in the United States in 1985 (OMNIA 1986). Brakes and gaskets are the primary applications using the pulp form of Kevlar® (DuPont 1986f); thus, about 10 percent of total Kevlar® production is in the form of pulp. Consumption of Kevlar® by the industries using pulp is expected to grow rapidly because Kevlar® is used as a replacement for asbestos in many of the pulp applications such as friction materials and gaskets (DuPont 1986f).

2. Fiber Use

The major uses of Kevlar® fiber include tire cords (one of the largest single uses); protective clothing, including ballistic protective clothing, heat and fire-resistant clothing, and cut-resistant clothing; industrial fabrics; high-performance composites; high-strength ropes and cables; and friction materials. Tire cords, composites, and ropes and cables are likely to be made from continuous filament yarns. Industrial fabrics and protective clothing may be made from either continuous filament yarn or staple fiber. Friction materials are produced from Kevlar® pulp.

Kevlar® fiber, when abraded, forms fine fibrils on the surface of the core fiber; these fibrils may have diameters of less than one micron (Merriman and Norman 1981). If these fibrils split off from the core fiber, they could become airborne and would be of respirable size.. Kevlar® pulp is produced

Table 3. DuPont's Monitoring Data for Pulp-Making Operations

Operation	Date	Sampling Time	Number of Samples	Maximum Count (fibers/cc)	Range, Excluding Maximum (fibers/cc)
E[a]	1985	2-4 Hours	14	0.28	0.02-0.25
		80 Minutes	80	0.30	0.02-0.17
F[b]	1981	1.5-4 Hours	5	0.09	N.D.[c] -0.03

[a] Preliminary data.

[b] Maximum likely 8 hour TWA exposure: 0.1 fibers/cc.

[c] N.D. (Not Detected) is below the limit of detection, 0.01 fibers/cc.

NOTES: NIOSH 7400 and P & CAM 239 methods were used. Samples were analyzed using phase contrast optical microscopy. Results may include both area and personal monitoring (DuPont 1986a); Operation E, 80 minutes, may be area monitoring.

Source: DuPont 1985, Attachment IV.

by a process of abrasion, giving highly fibrillated fibers. Therefore, the pulp form of Kevlar®, with many fine fibrils, probably has a higher potential for airborne fiber release during manufacturing processes than staple, continuous filament, or short fiber. In practice, however, monitoring results for pulp manufacture (see Table 3) and use show low fiber counts, indicating that the fibrils do not tend to split off from the core fiber or, if they do, they do not tend to become airborne. Kevlar® fibers have a tendency to clump together, according to several sources (DuPont (n.d.)c; Griffin Wheel Co. 1986); this characteristic might limit the fibers' ability to become airborne.

Kevlar® pulp is available in dry form, packaged in 10-pound bags, or as wet lap (paper-like rolls of material containing 55 percent water). Dry pulp is used primarily in the manufacture of friction products including disc brake pads, drum brake linings, truck brake blocks, clutch facings for manual transmissions, and industrial friction products. Dry pulp may also be used for compressed sheet gasketing. Wet lap is used in paper making; Kevlar® paper products include gasketing paper and some types of friction materials, such as automatic transmission paper and friction materials for oil-based brakes and clutches in off-highway vehicles. Friction products made with dry pulp probably consume by far the largest quantity of Kevlar® pulp (Littleford 1986). Of the friction products made from Kevlar®, brake blocks for trucks are probably the largest-volume product; between 10 and 50 percent of trucks may be equipped with non-asbestos brake blocks, with Kevlar® one of the major asbestos substitutes in use (ICF 1985). Drum brake linings for automobiles is a Kevlar® application with high growth potential; most automobiles are equipped with drum brake linings in the rear, predominantly made from asbestos at present, and Kevlar® is currently the only asbestos substitute available (ICF 1985). Manufacturing processes using Kevlar® pulp are discussed in detail in the following sections because they are the manufacturing processes most likely to lead to respirable airborne fiber exposure. Short fiber products may also be produced by the same processes. No information was available on production volume or capacity for products made from Kevlar® pulp.

a. Friction Materials (Except Paper)

Most friction materials are made using dry Kevlar® pulp. According to DuPont product literature, short fibers may also be used (DuPont (n.d.)c), but no users of short fibers could be identified. The major supplier of equipment for processing Kevlar® pulp and short fiber confirms that the majority of manufacturers use the pulp form (Littleford 1986). It is possible that some manufacturers may use short fibers along with pulp (fiber mixtures are often used), and others may use only the short fiber. The processes used would be essentially the same for pulp and short fiber. Other fibers, such as processed mineral fibers or ceramic fibers, may also be included in the formulations for friction products; the composition of these products is considered proprietary.

Dry Kevlar® pulp consists of fibers 1/2 to 8 millimeters in length (average length 4 millimeters) or 1/2 to 4 millimeters in length (average 2 millimeters). The pulp diameter is 12 microns, but the fibers have sub-fibers or fibrils attached to their surfaces that may be less than one micron in diameter (Merriman and Norman 1981); if these fibrils split off from the core fiber, they may be respirable. Kevlar® short fiber is 1/4 inch (6 millimeters) or 1/2 inch (13 millimeters) long and 12 microns in diameter (DuPont (n.d.)a).

Friction products may be manufactured from Kevlar® using either a wet-mix or a dry-mix process. These processes may vary by manufacturer, raw materials used, and product; products usually manufacturing using a dry-mix process and those usually manufactured by a wet-mix process are discussed separately in the following sections. The dry-mix process appears to have the highest potential for fiber release because the fiber remains in the dry state through several processing steps. Most manufacturers were reluctant to describe their processes in detail; therefore, manufacturing steps are discussed generally.

(1) Friction Products Probably Produced Using a Dry-Mix Process

Manufacturers. Friction products usually produced using a dry-mix process include disc brake pads for automobiles, brake blocks for heavy vehicles (Krussel and Cogley 1982), and industrial friction products, which are often similar to brake blocks. (The industrial friction category may include a wide variety of products, some of which may be produced by a wet-mix process.) Manufacturers of aramid dry-mix friction products are shown in Table 4. Eleven individual manufacturers were identified, with plants in 14 locations; three produce more than one type of product. We did not confirm that each of these manufacturers uses the dry-mix process, but the dry-mix process is the most likely production process for each of these product types.

Manufacturing Process/Potential Exposure Points. The dry-mix process consists basically of the following steps, although there may be variations:

- Mixing of fibers, dry resins, and property modifiers;
- Molding and curing using heat and pressure;
- Finishing by grinding and drilling; and
- Packaging of finished product.

Table 4. Manufacturers of Friction Materials Probably Produced Using Dry Aramid Pulp and Dry-Mix Process

Company	Location
MANUFACTURERS OF DISC BRAKE PADS FOR LIGHT AND MEDIUM VEHICLES	
Abex Corporation	Winchester, VA
Bendix Corporation	Troy, NY
Guardian Corporation	Brighton, MA
Nuturn	Smithville, TN
P.T. Brake Lining Company	Lawrence, MA
MANUFACTURERS OF BRAKE BLOCKS FOR HEAVY VEHICLES	
Brake Technology Company	Lawrence, MA
Carlisle Corporation	Ridgway, PA
H.K. Porter Company (Thermoid Division)	Huntington, IN
Nuturn	Nashville, TN
P.T. Brake Lining Company	Lawrence, MA
Raymark Corporation	Stratford, CT
MANUFACTURERS OF INDUSTRIAL FRICTION PRODUCTS	
Nuturn	Nashville, TN
National Friction Products	Logansport, IN
Bur Bilt Products Corp.	Canton, OH
Raymark Corporation	Manheim, PA

Sources: ICF 1985; DuPont (n.d.)b; Telephone calls to manufacturers.

Kevlar® pulp is supplied in 10-pound bags. According to one user, the pulp is removed from the bag as a tightly-packed mass of curled and tangled fibers which remain in a clump rather than separating and releasing fibers to the air (Griffin Wheel 1986).

Because Kevlar® fibers tend to clump together, they generally require opening or fluffing for uniform mixing (DuPont (n.d.)c). Fluffing is generally performed in a rotating-blade mixer into which other ingredients are added after fluffing; however, some companies might use a separate process for fluffing (Carlisle 1985). The mixing process basically consists of blending all raw materials, which may include from six to two dozen ingredients (Carlisle 1985), in the closed mixer. The major equipment manufacturer for aramid processing recommends mixing of all the dry ingredients in a mixer with plow-shaped mixing elements and high-speed fiber opening disperser blades for about 10 minutes. The same mixing process is recommended for both the pulp and short fiber forms of Kevlar® (Littleford 1982a, 1982b).

Mixing is followed by forming, pressing, and curing, using heat and pressure. Each of these procedures may involve several steps; the companies interviewed were not willing to provide process details. The raw material mix remains in a dry state until it is cured.

The finishing process involves cutting to specifications, grinding, and boring holes; the finishing process is fairly labor intensive (Carlisle 1985). While machines carry out each step in the manufacturing process, workers operate the machines. Friction products must meet specifications, which necessitates checking the machined products frequently and adjusting the machinery as necessary (Carlisle 1985).

There appears to be considerable variation in the degree of automation within the friction products industry. Most manufacturers would not supply details on processes and level of automation due to the proprietary nature of their processes. One truck block manufacturer reported that their process was automated as much as possible to minimize handling. The fiber is conveyed automatically to the mixer (bag-opening is manual, however); other specific details of automation were not supplied (Brake Technology 1986a). A manufacturer of industrial friction materials indicated that there was very little automation in their operations (National Friction Products 1986). Materials may be carted by hand from one process step to another, or they may be moved automatically. Bendix Corporation, one of the largest friction materials manufacturers (their aramid product volume is very low, however), reports that materials are hand-carried between process steps (Bendix 1985).

Carlisle Corporation claims that friction products manufacturing generates large quantities of dust; however, no information about the quantity or the fiber content of the dust is available. In general, Carlisle claims that the friction products industry is very concerned with possible hazards because of its experience with asbestos. Dust-capturing equipment is usually used, and all companies have safety engineers (Carlisle 1985). Brake Technology Company says that they assume that no fibers are safe, including aramid, and act accordingly (Brake Technology 1986a).

All the companies interviewed use some type of vacuum system to control dust and fiber. Many friction product manufacturers produce aramid products in the same plant as asbestos products, often using the same equipment. Equipment used by Carlisle and Bendix includes dust-catching equipment consisting of exhaust hoods with strong suction over every processing step (Carlisle 1985; Bendix 1985). Brake Technology, which produces only non-asbestos friction products, also uses dust-catching equipment (Brake

Technology 1986a). Also, there is usually frequent vacuuming of the floors in these plants (Carlisle 1985).

Personal protective equipment used by workers during dry-mix friction products manufacture appears to vary from company to company. Workers at Brake Technology wear disposable uniforms, dust masks, and protective hats in areas where material is in an uncured state (i.e., mixing, pre-forming, and hot-pressing) (Brake Technology 1986). Carlisle reports that respirators are available, but not required, for non-asbestos workers (Carlisle 1985). Workers at National Friction Products do not wear any type of protective clothing (National Friction Products 1986). Bendix employees involved with non-asbestos fibers probably do not wear protective clothing (Bendix 1986).

<u>Extent of Potential Exposure</u>. Exposure to airborne aramid fibers is possible during the dry-mix mixing and molding steps (ie., before curing of the product), and during product finishing operations. Most of the companies contacted would not provide information on the number of workers exposed to airborne fibers during the manufacture of dry-mix friction products or on the duration of exposure. At Brake Technology, 70 to 80 people are involved in the mixing and molding processes (Brake Technology 1986b). Operations are carried out every day for three shifts (Brake Technology 1986a). Operations are probably full time for most of the brake block manufacturers listed since aramid-based brake blocks are well-known and widely used. Some of the other aramid products may still be in the developmental stage and would not, therefore, be produced on a full-time basis. Bendix, a producer of automotive disc brake pads, currently produces aramid products only about two days per week, and only two or three employees are involved in operations in which the fiber is in a dry state (Bendix 1986).

Dupont provided monitoring data for airborne dust levels at a friction products manufacturing plant which used a dry-mix process, with Kevlar® feed in the form of dry pulp (DuPont 1986a). This plant belongs to one of DuPont's customers and was monitored by DuPont in 1982 using the sampling and analytical methods described for DuPont's fiber cutting and pulp-making operations above. Monitoring results are presented in Table 5. Seventeen samples were taken, and the results showed a range of airborne fiber concentrations from 0.01 to 0.07 fibers/cc of air. The maximum likely eight-hour time weighted average (TWA) exposure is less than 0.1 fibers/cc. DuPont has suggested a workplace exposure limit of 5 fibers/cc (8-hour TWA) to its customers (DuPont 1985).

(2) Friction Products Probably Produced Using a Wet-Mix Process

Manufacturers. Friction products usually produced using a wet-mix process include drum brake linings for light and medium vehicles (i.e., passenger cars and light trucks), railroad brakes, and clutch facings for manual transmissions (clutch facings may also be produced by a dry-mix process). Table 6 presents a list of the manufacturers who produce these products; four producers of drum brake linings, one railroad brake producer, and one manufacturer of clutch facings were identified. These products are manufactured at a total of five plants.

Manufacturing Process/Potential Exposure Points. The wet-mix process consists of the following steps, with possible variations by product and manufacturer:

- Mixing of fibers, solid and liquid resins, property modifiers, and solvents;
- Extrusion or rolling;
- Molding and curing using heat and pressure;

Table 5. DuPont's Monitoring Results for Friction Materials Plant, Dry-Mix Process

Date	Sampling Time	Number of Samples	Maximum Count (fibers/cc)	Range, Excluding Maximum (fibers/cc)
1982	4-7 Hours	11	0.05	0.01-0.04
1982	1.5-3.5 Hours	6	0.07	0.01-0.03
Maximum likely 8 hour TWA exposure: less than 0.1 fibers/cc				

NOTE: NIOSH 7400 and P & CAM 239 methods were used. Samples were analyzed using phase contrast optical microscopy. Results may include both area and personal monitoring (DuPont 1986a).

Source: DuPont 1985, Attachment IV.

Table 6. Manufacturers of Friction Materials Probably Produced Using Dry Aramid Pulp and Wet-Mix Process

Company	Location
DRUM BRAKE LININGS FOR LIGHT AND MEDIUM VEHICLES	
Abex Corporation	Winchester, VA
Bendix Corporation	Troy, NY
Nuturn	Smithville, TN
P.T. Brake Lining Company	Lawrence, MA
RAILROAD BRAKES	
Griffin Wheel Company	West Chicago, IL
CLUTCH FACINGS (MANUAL)	
Nuturn	Smithville, TN

Sources: ICF 1985; DuPont (n.d.)b; Telephone calls to manufacturers.

- Finishing by grinding and drilling; and
- Packaging of final product.

As discussed in the section on the dry-mix process, Kevlar® pulp, as it comes from its package, is a tightly packed mass of fibers. As with the dry-mix process, fluffing of the fibers is required for proper mixing. The equipment manufacturer recommends adding the fiber, dry resins, fillers, and additives to a mixer with plow-shaped mixing elements and high-speed fiber opening disperser blades, and mixing in the closed mixer for 2-4 minutes to fluff the fibers and mix the dry ingredients. Liquid resins and solvents are added after the fluffing in complete, and the raw materials are mixed for 5-10 minutes to uniformly mix and disperse the fibers into the wet medium.

If short fiber rather than pulp is used, one of two methods is recommended, depending on the relative wetness of the final mix. For a relatively dry mix using viscous resins, the fiber alone should be fluffed for 3-6 minutes and then discharged. The remaining components should be added to the mixer and be fully mixed and dispersed. The fluffed fibers are then added to the rest of the mix, and mixing is carried out for an additional 5-10 minutes. In the case of a relatively wet mix, fluffing and mixing procedures are similar to those used for pulp (i.e., the fiber and dry ingredients are mixed and fluffed, and then the liquid ingredients are added) (Littleford 1982a, 1982b).

In contrast to the dry-mix process, fibers are no longer in a dry state following the mixing step in the wet-mix process. Mixing is followed by extrusion or rolling. As with the dry-mix process, the material is molded and cured, using heat and pressure. The product is ground to its final shape and drilled; the finished product is then packaged.

At Griffin Wheel Company, which produces only Kevlar® brake products, there are fewer than 100 employees; however, not all of them are directly exposed to Kevlar® fiber. Manufacture of Kevlar® products is a full-time operation, three shifts per day, five days per week (Griffin Wheel 1986). At Bendix, as reported in the previous section, two to three employees work in areas where Kevlar® is present in the dry state, and Kevlar® operations take place about two days per week (Bendix 1986).

According to Griffin Wheel, monitoring for asbestos was performed before the company converted to Kevlar®. Monitoring always showed airborne fiber concentration at least 100 times below the OSHA Permissible Exposure Limit (PEL) of 2.0 fibers/cc for asbestos (recently changed to 0.2 fiber/cc) (actual data were not available). The same equipment is now used for processing and control of aramid fiber, and fiber concentration is also expected to be low (Griffin Wheel 1986).

b. Compressed Sheet Gasketing

(1) Manufacturers.

Two manufacturers of compressed sheet gasketing material made from Kevlar® were identified. They are:

- Victor Products Division of Dana Corporation, Robinson, IL; and
- Garlock, Inc., Palmyra, NY.

(2) Manufacturing Process/Potential Exposure Points

Process Description and Automation. Compressed sheet gasketing is made from dry Kevlar® pulp using a wet-mix process. The recommended procedure for mixing is the same as that described for wet-mix friction materials; that is, the fiber and dry ingredients are fluffed in the mixer, followed by the addition of liquid ingredients and further mixing (Littleford 1982a). The mixed product is a dispersed agglomerated mass. This

As with the dry-mix process, manufacturers provided few details about manufacturing operations involving the wet-mix process; however, there appears to be variation in level of automation in the industry. The railroad brake manufacturer indicated that its operations are highly automated. Following manual bag-opening, raw materials are conveyed to the mixer automatically, and the process is continuous; materials are not transferred manually from one place to another (Griffin Wheel 1986). On the other hand, Bendix, as discussed in the section on the dry-mix process, is not highly automated (Bendix 1985). Level of automation may also vary somewhat with the type of product being produced. Some types of friction products may require more careful handling than others; and, therefore, the manufacturing process may be more labor intensive. For example, drum brake linings, because of their arc-shape, may tangle and must, therefore, be piled carefully (Bendix 1985).

All of the companies using the wet-mix process reported using vacuum systems to control dust during manufacture. Griffin Wheel Company, which produces railroad brakes, describes the control used as a negative pressure system in the area where fibers are conveyed to the mixer (Griffin Wheel 1986). Nuturn and Bendix use vacuum-type dust collection systems (Bendix 1985, Nuturn 1986).

Personal protective equipment was not used by workers in any of the companies contacted, although Nuturn said that protective clothing would be used if monitoring showed "excessive" fiber in dust ("excessive" was not defined) (Nuturn 1986).

Extent of Potential Exposure. The major areas of potential fiber exposure during manufacture using the wet-mix process are introduction of fiber to the mixer and finishing by grinding and drilling. Most companies did not provide data on number of workers at various stages of the process.

mass is transferred to a series of hot and cold rollers, and the process becomes essentially continuous. Curing takes place during the rolling step; there is no separate curing process (Garlock 1986). The raw material is squeezed between the rollers to a desired thickness, calendered to the appropriate width, and cut to the desired size and shape.

At Victor Products Division of Dana Corporation, fiber bags are manually opened and emptied into the mixer, whereas at Garlock, Inc., fiber bag opening and feeding is automatic. The only operator interaction at Garlock is the loading of plastic-enclosed bales of fiber onto a conveyor; the process at Garlock is a completely closed system from beginning to end. Victor Products Division's process requires manual emptying of mixers onto a conveyor which carries the mix to the closed calendering process (Victor Products Division 1985; Garlock 1985).

Engineering Controls and Protective Equipment. Hoods are used at the Victor Products Division operation; the hoods are for solvent fumes mitigation, not fiber control. Masks are available but are not required for non-asbestos workers (Victor Products Division 1985).

(3) Extent of Potential Exposure

Number of Persons Directly/Indirectly Exposed. Victor Products Division's manual de-bagging and fiber emptying processes for compressed sheet gaskets generally involve one operator per batch. This one operator is capable of running several mixers at once because his involvement halts during mixing (Victor Products Division 1985). Garlock's operation requires one operator to load bales and one operator to remove finished products from the completely closed, automatic line; a third operator mans the control room (Garlock 1985).

Duration of Exposure. Garlock's operation is full-time, three shifts per day, six days per week (Garlock 1986). Victor Products Division also produces sheet gasketing full time, but part of their production is asbestos sheet gasketing rather than the Kevlar® product. The ratio of production of the Kevlar® product to the asbestos product was not available (Victor Products Division 1986).

Monitoring Data. In 1982, DuPont monitored airborne aramid fiber levels at one of its customers' plants which manufactures compressed sheet gasketing material using the sampling and analytical methods described for DuPont's fiber cutting and pulp making operations above. Monitoring results are presented in Table 7. The maximum aramid fiber count of the five samples taken was 0.09 fibers/cc; the range of the other samples was 0.01 to 0.04 fibers/cc. The maximum likely eight-hour time weighted average (TWA) exposure is less than 0.1 fibers/cc. DuPont has recommended to its customers an exposure limit of 5 aramid fibers/cc for an eight-hour TWA (DuPont 1985).

c. Aramid Paper Products

Aramid pulp for papermaking is in the form of wet lap, a type of coarse paper, sold in rolls, containing 55 percent water. Like dry pulp, the pulp fiber is available in two lengths: 1/2 to 8 millimeters (averaging 4 millimeters) or 1/2 to 4 millimeters (averaging 2 millimeters). The pulp core diameter is 12 microns, but the pulp contains fibrils that may be less than one micron in diameter (Merriman and Norman 1981). Wet lap is reslurried for use, and normal papermaking processes are used in the production of paper products from Kevlar®.

Table 7. DuPont's Monitoring Results for Compressed Sheet Gasketing Plant

Date	Sampling Time	Number of Samples	Maximum Count (fibers/cc)	Range, Excluding Maximum (fibers/cc)
1982	8 Hours	3	0.04	0.01-0.02
1982	3-4 Hours	2	0.09 (both samples)	-
Maximum likely 8 hour TWA exposure: less than 0.1 fibers/cc				

NOTE: NIOSH 7400 and P & CAM 239 methods were used. Samples were analyzed using phase contrast optical microscopy. Results may include both area and personal monitoring (DuPont 1986a).

Source: DuPont 1985, Attachment IV.

(1) Manufacturers

Four manufacturers of aramid paper products were identified (see Table 8). Two manufacturers make off-highway friction materials which are paper products designed for use in oil-filled brakes and clutches for off-highway vehicles such as tractors and mining trucks. One manufacturer makes gasketing paper and paper for clutch facings for automatic transmissions (another type of friction material). The fourth company, Mead Paper, has several aramid paper products in development. These products are considered proprietary, and we were unable to obtain information about them (Mead Paper 1986).

(2) Manufacturing Process/Potential Exposure Points

The process used to make Kevlar® paper is similar to that used to make fiberglass paper. The level of automation and the use of engineering controls and protective equipment are also similar. Refer to Chapter VII, Fiberglass, Section B.1 for a detailed description of the paper manufacturing process. Papermaking is a semi-automatic process, with raw materials being pulped in batches and fed to a continuous papermaking machine. When Kevlar® pulp is used, rolls of wet lap are added directly to the pulper (following removal of the wrapper) (Lydall 1986a). Rolls of finished paper are cut from the machine and removed manually for packaging or further processing. The cutting and finishing operations have the potential to generate airborne fibers; local ventilation is used in these areas. Personal protective equipment is not used.

(3) Extent of Potential Exposure

For the production of Kevlar® paper at Lydall, Inc., one person unloads rolls of Kevlar® wet lap and puts it into storage (packages are unopened at this point). Two handlers are involved in the pulping

Table 8. Manufacturers of Kevlar® Paper Products

Company	Location
OFF-HIGHWAY FRICTION MATERIALS	
Raymark	Crawfordsville, IN
S.K. Wellman	Bedford, OH
AUTOMATIC TRANSMISSION PAPER	
Lydall, Inc.	Covington, TN
GASKET PAPER	
Lydall, Inc.	Hoosick Falls, NY
PAPER PRODUCTS IN DEVELOPMENT	
Mead Paper	South Lee, MA

Sources: DuPont (n.d.)b; Telephone calls to manufacturers.

operation (rolls of wet lap are added to the pulper for reslurrying), and three in the papermaking operation; the material is wet during all stages of these operations. Three workers are involved in drying the paper, and one or two workers are engaged in packaging the product. Papermaking from Kevlar® takes place once or twice per month in runs of eight to ten hours (Lydall 1986). Raymark's papermaking operation (friction materials for off-highway vehicles) is also a small-volume operation (Raymark 1986).

d. Other Pulp Uses

According to DuPont product literature, Kevlar® pulp may be used for cement reinforcement and reinforcement of phenolic plastics (DuPont (n.d.)a, (n.d.)c). We have been unable to identify any manufacturers making these types of products. According to the major manufacturer of Kevlar® pulp processing equipment, Kevlar®-reinforced cement products are in development by several manufacturers, and such products may be in production in Europe (Littleford 1986); we have not confirmed this information.

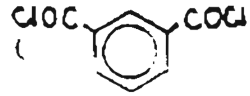
B. Nomex®

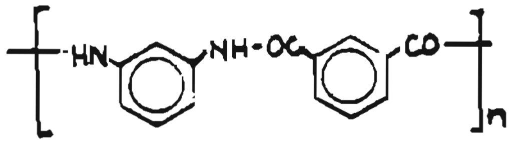
1. Fiber Production

a. Fiber Producers

Nomex® fiber, like Kevlar® fiber, is produced by DuPont at the Spruance Fiber Plant which has 3,500 employees (Dun and Bradstreet 1986); there are 500 production workers for aramids (Nomex® and Kevlar® combined) (DuPont 1986e). DuPont would not provide any data on current Nomex® capacity or production. Capacity was reported to be about 20 million pounds in 1975 (Preston 1978); in December 1985, DuPont announced a two-year plan to increase Nomex® capacity by about 20 percent (Chemical Marketing Reporter 1985).

b. Fiber Production Process/Potential Exposure Points

Nomex® is produced by the polymerization of m-phenylenediamine () and isophthaloyl chloride () to give poly(m-phenyleneisophthalamide), which has the following structure:



The polymerization process is shown in Figure 3. Nomex® is prepared in solution at a low temperature and, like Kevlar®, is spun out of solution. However, it is likely that a dry-spinning process is used in the case of Nomex®, since the polymer is spun out of an organic solvent, instead of the wet-spinning process used for Kevlar®. One source describes the preparation of a Nomex®-like fiber by a method believed to be similar to that used for Nomex®. The fiber is dry-spun through orifices of 0.13 mm diameter into hot air at 200-210°C. It is wound up at a speed of 125 meters per minute. The wound fiber is extracted with cold water for 64 hours, and then drawn to 5.5 times its original length in steam at 56 pounds per square inch pressure (Moncrieff 1975). Other procedures following spinning of the fiber are probably similar to those described earlier for Kevlar®. The processing of Nomex® fiber is shown in Figure 4.

Nomex® fiber is sold as continuous filament and is also cut into staple fiber, as is Kevlar®. Nomex® is not sold as short fibers or pulp; however, it is chopped into short fibers for use internally in papermaking (discussed below.) No information is available on fiber-cutting procedures used.

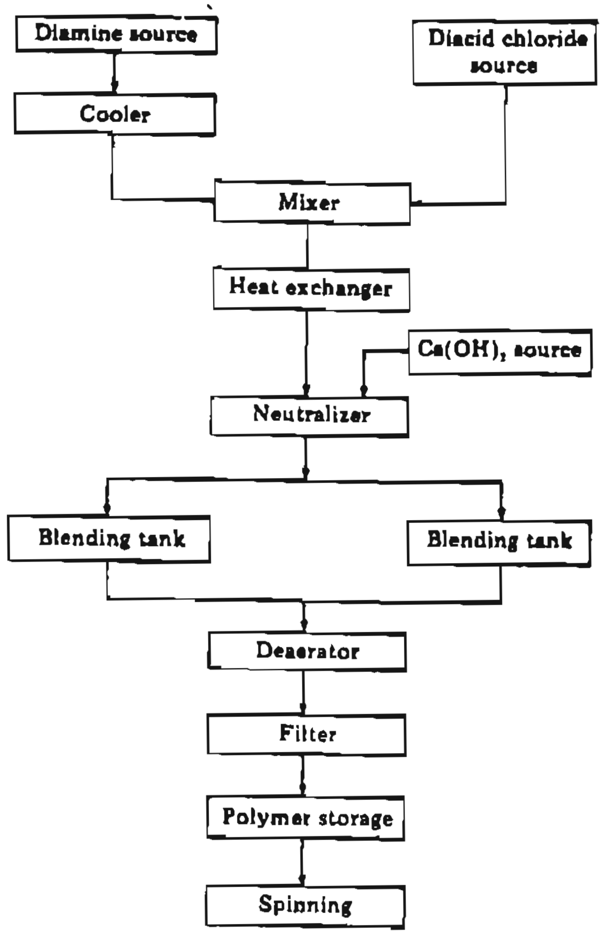


Figure 3. Preparation of Nomex®. (NOTE: The reactants are m-phenylene-diamine and isophthaloyl chloride; the solvent is dimethylacetamide. Polymerization is carried out in solution.) (Source: Preston 1978, p. 230.)

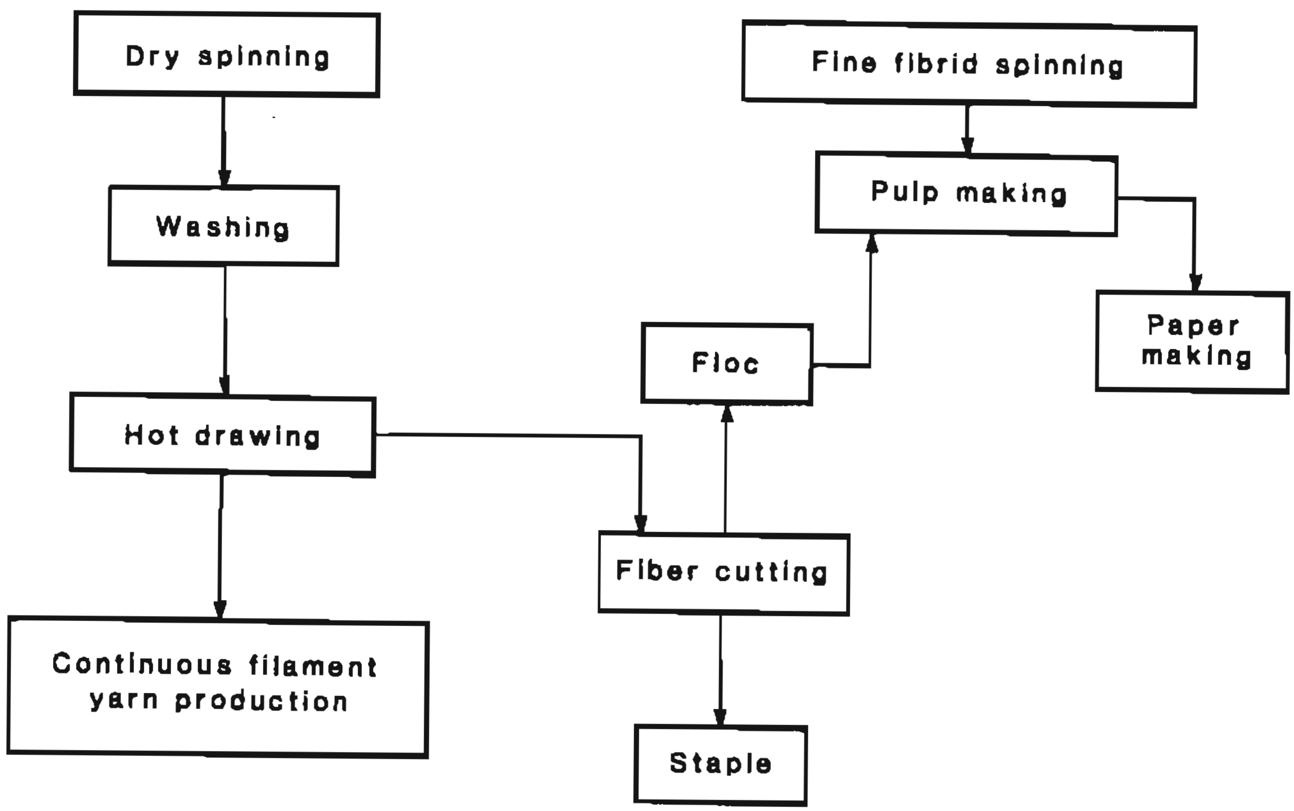


Figure 4. Nomex® fiber processing. (Source: ICF, based on DuPont 1985, DuPont 1981, Moncrieff 1975, Preston 1978, Rebenfeld 1983, USEPA 1982).

A large fraction of Nomex® production is in the form of paper, which is made only by DuPont at its fiber-production facility. Therefore, we will consider Nomex® paper to be a primary form of Nomex® fiber, and its production will be discussed here. Nomex® paper is made from short Nomex® fibers (floc) and microscopic fibrous particles (fibrids) (DuPont 1981). To make Nomex® paper, the fibrids and floc are combined into a sheet by normal papermaking methods. That is, the fibers are mixed with water, followed by formation of a continuous pulp mat on wire screens. Water is removed from the mat by vacuum, and the mat is dried on steam heated rollers (see Section B.1 of Chapter VII, Fiberglass). The fibrids form filmy webs in the spaces between the floc fibers, and no other binders or fillers are used. The paper is subsequently calendered at high temperature and pressure (DuPont 1981). Winding, cutting, and packaging of the paper follows.

Because the fibrids used in the production of Nomex® paper are apparently of very fine diameter (fiber size is not available), their production is of some interest. According to DuPont, these fine fibers, which are produced only as intermediates for Nomex® paper, are produced directly in a water bath. These fibers are never present in a dry form and are never stored (DuPont 1986a). Production details are not available; however, presumably Nomex® polymer solution is forced through a fine spinneret directly into a water bath. The floc used for Nomex® paper is chopped Nomex® filament. Floc is used only internally for papermaking; floc is not a commercial product. Its diameter is approximately 12 microns; its length was not available (DuPont 1986b).

Nomex® production, like Kevlar® production, is a continuous, automated process, involving little worker contact (DuPont 1986d). No information was available on engineering controls and personal protective equipment used during Nomex® production.

c. Extent of Potential Exposure

As in the case of Kevlar®, the maximum number of people potentially exposed to Nomex® fiber during production is 500, the total number of aramid (Nomex® and Kevlar®) production workers (DuPont 1986e). Nomex® is produced 365 days per year (DuPont 1986c). The number of shifts per day is proprietary (DuPont 1986a); it is likely, however, that there are three shifts per day.

DuPont has provided job titles and descriptions for Nomex® production employees. The titles and descriptions for Nomex® spinning and textile workers are as follows (DuPont 1986e):

- Production Machine Operator, P&R/S&T (Polymer & Recovery/Spinning & Textile) -- Operates spinning and wash draw machines.
- Production Machine Operator, P&R/S&T -- Operates crimpling and baling equipment, transports product.
- Production Machine Operator, P&R/S&T -- Breakdown, clean, inspect, assemble spin packs.
- Finishing Machine Operator, P&R/S&T -- Assist string-up, doffing, wash winders.
- Finishing Machine Operator, P&R/S&T -- Operates cutter and crimping equipment; operates rewinder, interlace jets, baler; inspects product and prepares finish.

DuPont did not provide the number of employees for each job title.

As mentioned earlier, there is no potential for fibril formation with Nomex® (DuPont 1986a). DuPont reports that monitoring of Nomex® production operations shows airborne fiber concentrations below the limit of detection (less than 0.01 fibrils/cc) for five full-shift fixed area samples collected using membrane filters and a sampling pump (using NIOSH method P &

CAM 239). Personnel in the areas monitored include production machine operators for crimping and baling equipment, and finishing machine operators (see job titles and descriptions above) (DuPont 1986e).

Job titles and descriptions for Nomex® paper production employees are as follows (DuPont 1986e):

- Chemical Process Operator -- Operates paper machine.
- Production Machine Operator -- Operates fibridation, drum filters, and related equipment.
- Production Machine Floc Operator -- Operates floc cutter, stock preparation equipment, and calender.
- Finishing Machine Operator -- Maintains essential materials inventory, production records, operates cutting and packaging machines, inspects finished product, shreds and bales waste, boxes floc and fibrids, miscellaneous assignments.

No information was provided on the number of employees for each job category.

DuPont has not reported any monitoring data for Nomex® paper production. There appears to be little potential for exposure to the fine fibrids used in the production of Nomex® paper and, according to DuPont, abrasion of Nomex® does not produce fibrils; therefore, it is likely that airborne fiber concentrations would be low during Nomex® paper production.

2. <u>Fiber Use</u>

Nomex® fiber is produced by DuPont in the form of paper (which may account for as much as half of the total production), staple, and continuous filament yarn (ICF 1986). The major use of Nomex® paper is as electrical insulation for motors and transformers. The paper may be used directly or it may be cut, shaped, and coated by secondary manufacturers into fabricated parts used for electrical insulation. Some Nomex® paper is also used in composites. Major applications of Nomex® staple and continuous filament are industrial filter bags for hot gas emissions, protective clothing, and coated fabrics.

Nomex® is not produced in the form of pulp or short fiber. According to DuPont, it has no potential for splitting into smaller diameter fibers or fibrils (DuPont 1986a). Therefore, the potential for exposure to airborne fiber during manufacturing processes appears to be small; therefore, Nomex® uses are not considered in detail.

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III. ATTAPULGITE

A. Fiber Production

World production of attapulgite in 1983 was estimated at approximately 1.2 million tons (Industrial Minerals 1985). The major producing countries are the United States (nearly 90 percent of world production), Senegal, Australia, South Africa, Spain, and India. U.S. exports, the bulk of which goes to Canada, accounts for about 11 percent of total production in the United States (ICF 1986).

1. Fiber Producers

Commercial production of attapulgite in the United States is centered in the southeastern part of the country. Georgia and Florida are the two principal attapulgite-producing states accounting for 90 percent of U.S. production in 1983 (Ampian 1983). Production in several other states, especially Texas, has begun recently.

There are three producers of gelling and non-gelling attapulgite in the United States (Industrial Minerals 1985):

- Floridin Company;
- Engelhard Minerals and Chemicals Corporation (hereafter referred to as Engelhard); and
- Milwhite Company.

All three firms maintain facilities within close proximity to one another and mine different areas of the same attapulgite deposit (Milwhite 1986a). The major difference between gelling and non-gelling grades is the particle size; gelling grades are more finely milled. Also, the gellant grades are used for their property of thixotropy; that is, gellant grades are liquid when agitated and gell-like when standing.

Floridin Company, a subsidiary of ITT Corp. is probably the largest producer of attapulgite. Floridin, which began operation in 1959, operates two attapulgite processing plants -- one in Quincy, Florida and one in Havana, Florida (ICF 1986, Floridin 1986a). Floridin markets attapulgite products under the trade names Florex, Min-u-gel, and Florigel H-Y (Industrial Minerals 1985).

Engelhard produces approximately 270,000 tons of attapulgite per year at its plant in Attapulgus, Georgia under the trade names Attasorb; Attapulgus 150, 350, 390; Pharmasorb; and Emcor 66 (Industrial Minerals 1985, Englehard Special Chemicals 1986a, ICF 1986).

Milwhite, which began operation in 1951, produces approximately 55,000 tons of attapulgite per year at its plant in Attapulgus, Georgia (ICF 1986, Milwhite 1986a). Milwhite's products are known as Gel B, Fert-o-gel, and Basco (Industrial Minerals 1985).

Producers of non-gelling attapulgite products include the Oil Dri Corporation of America (hereafter referred to as Oil Dri), which began operation in 1941, and Waverly Mineral Products Co. (hereafter referred to as Waverly), a division of Johnson-March Corporation in Meigs, GA (Dun & Bradstreet 1986). Oil Dri extracts attapulgite in Thomas County, Georgia for processing at its plant in Ochlocknee, Georgia. In 1984, the company mined 380,000 tons of clay (Industrial Minerals 1985).

2. Fiber Production Process/Potential Exposure Points

a. Process Description and Automation

(1) Mining

Attapulgite is mined by stripping methods. Bulldozers and scrapers remove the overburden which may be anywhere from 3 to 75 feet thick. The Oil-Dri Corp. is unique in that it uses a large walking electric dragline for stripping. Blasting may be necessary in the Attapulgus, GA and Quincy, FL area of the country because the overburden may contain deposits of limestone and cemented sandstone. Loaders then put the clay into trucks, and it is hauled to the processing plants via public highways (Patterson and Murray 1983).

(2) Milling

The processing of attapulgite requires only simple milling techniques. First, water and volatile matter must be removed. Then, the clay is ground to suitable sizes. Raw attapulgite may contain 50 percent volatile matter and 10 percent impurities, while processed attapulgite contains only 7 to 8 percent water. The milling operations are generally automated and enclosed. Although the Engelhard plant is automated to a certain extent, workers are needed to operate the milling machines, screens, and packaging operations.

In most plants, raw clay is fed into a slicer to break up large chunks before drying. Engelhard uses an extrusion process for its gellant and absorbent grades to enhance surface properties and viscosity. Crushed clay is fed into a pugmill, water is added, and the clay is extruded as rods of approximately 1/2-inch in diameter. The resulting noodles are dried in rotary driers under carefully controlled temperature conditions that are specific for each product. Chemicals are added to improve the gellant grades (Engelhard Specialty Chemicals 1986b).

Drying is accomplished in gas or oil-fired driers which may be 10 feet in diameter and 65 feet long. In Meigs, GA, the Floridin Co. employs a fluid bed dryer after the clay has been air dried. The initial drying reduces the moisture content. Drier temperatures vary from 150°C for colloidal grades (flowable gellant grades for fertilizer suspension) to 650°C for the absorbent grades (Patterson and Murray 1983).

In some plants, rods inside the rotary driers do the grinding. Powdered products are produced using roll and hammer mills and other pulverizers, followed by screens. Most clay is ground until it is 90 percent finer than 200 mesh. For special markets, clay may be ground to 95 percent finer than a 10 μm particle size. At Engelhard, the absorbent grades are roller milled, and the finer grades are further ground in a Raymond Mill. Gellant grades are subject to micronizing in air fluid energy mills, which reduces the particle size to only a few microns (Engelhard Specialty Chemicals 1986b).

The preparation of coarse absorbent grades is a beneficiation process because fine and medium-grained sand impurities in the attapulgite are contained in the size fraction that is discarded.

At Floridin, dried material is ground and screened to make regular volatile content material in various grades for shipment. Regular volatile content material readily breaks up in water. Some regular volatile content material is subjected to further high temperature drying at 975°F to make a low volatile content material which does not readily break up in water and is less absorbent than the regular volatile content material (Industrial Minerals 1985, Industrial Minerals and Rocks 1983).

Milled material is next packaged into multiwalled paper bags, some with plastic liners, for transportation by truck. Fiber drums are used to package specialty products in small quantities. Metal drums with a 100-pound capacity are also used. Animal litter is packaged in 10-30 pound bags. Attapulgite bagging machinery requires operators to insert and remove bags.

The processing of attapulgite clay is presented schematically in Figure 1.

b. Engineering Controls and Protective Equipment

An industrial hygiene study of the Engelhard facility by NIOSH in 1977 (Zumwalde 1977) showed that the dust concentration for milling and

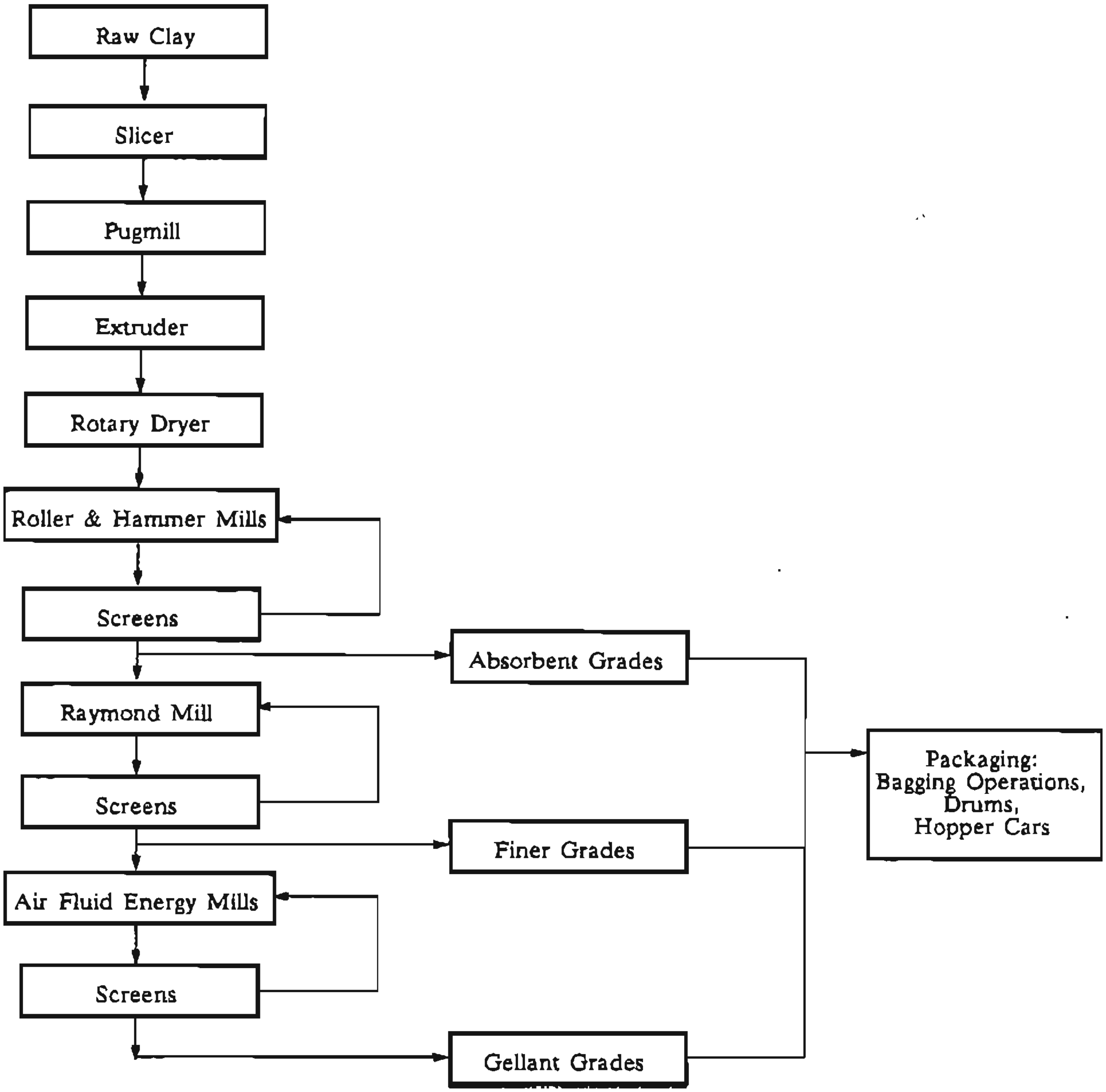

Figure 1. Attapulgite clay processing at the Engelhard Specialty Chemicals Plant in Attapulgus, Georgia. (Source: Industrial Minerals 1985.)

bagging operations was sometimes greater than nuisance dust standards (see Section 3 below). There was a potential for excessive airborne concentrations of dust for millers, shippers, laborers, and screen operators. However, because of the mobility of the workers within some of the job categories, these high concentrations were not demonstrated in their time-weighted averages (Zumwalde 1977). In 1975, Engelhard improved the local exhaust ventilation at its bagging stations and installed a new bagging system on one of its production lines.

The Engelhard plant is still quite dusty throughout and especially so near the bagging operations (Engelhard Specialty Chemicals 1986b) (see Section 3 below). All workers at Engelhard wear safety glasses or goggles and dust masks, to reduce inhalation of airborne dust. Gloves and coveralls are not required by Engelhard. Respirators are worn only during maintenance procedures (Engelhard Specialty Chemicals 1986b).

Transfer of the clay as it is processed occurs on belt conveyors, gravity flow chutes, and bucket elevators. These transfer systems are all enclosed and equipped with local vacuum systems that remove dust from the air and collect it in baghouses. Vacuum system dust collectors are widespread in the dustier areas of the plant (Engelhard Specialty Chemicals 1986b).

At the Milwhite plant, the level of dust increases considerably after the drying operation. More dust is generated as the clay approaches the bagging operation and particles become finer. The areas near the grinding and screening machines are particularly dusty. One screening station uses an air separator which blows the fine particles away from the heavier ones and causes dust to become airborne (Milwhite 1986b). Grinding and screening workers are required to wear MSHA approved dust masks and safety goggles or glasses.

Gloves and coveralls are not required by Milwhite (Milwhite 1986b, Milwhite 1986c).

As in the Engelhard plant, transfer of the processed clay at Milwhite is by belt conveyor, bucket elevators, and screw conveyors. All of these devices are enclosed by metal casings to eliminate airborne dust. No pneumatic systems are used to transfer the clay (Milwhite 1986c).

3. Extent of Potential Exposure

a. Number of Persons Exposed

Three hundred persons work in the production of attapulgite clay at the Floridin Co. plant in Quincy, FL (Dun & Bradstreet 1986). Approximately 355 persons work at the Engelhard milling operation, and 90 percent of them are in daily contact with the attapulgite clay. Engelhard has only one production line, but there are many processing options along that line to produce different products (Engelhard Specialty Chemicals 1986b). Engelhard did not indicate the number of workers involved in their mining operation.

There are 40-45 employees who are in direct contact with the clay mining and milling operations daily at Milwhite. It may be assumed that these figures include all shifts; each worker is exposed to the clay for five eight-hour shifts per week.

b. Respirability of Airborne Fibers

Studies indicate that American attapulgite fibers have an average length of 0.5 µm. Over 50 percent of the particles were found to be less than 0.4 µm in length. No information on the fiber diameter is available (Engelhard Specialty Minerals 1985).

All industry sources interviewed agree that attapulgite particles are certainly shorter than 1 µm but disagree with the classification of attapulgite as a fiber. Attapulgite is not a fiber in the sense that asbestos is (Floridin 1986a, Engelhard Specialty Chemicals 1986a, Milwhite 1986a). Attapulgite is often used in combination with co-fibers like fiberglass for the reinforcement properties that such fibers lend to the composite. Attapulgite is best characterized as a thixotropic gelling agent used to hold co-fibers together in a cohesive unit as in brake pads. Rather than being fibrous, attapulgite is rod or spicule shaped (Floridin 1986a, Engelhard Specialty Chemicals 1986a, Milwhite 1986a).

Table 1 presents the respirable and total masses of airborne attapulgite to which each type of worker in the Engelhard plant are subjected. NIOSH collected approximately 200 airborne samples at the various milling operations of which 150 were personal breathing zone samples, to determine time-weighted average exposures to respirable and total dust. Since there is currently no specific occupational health standard for attapulgite clay, the standards for inert or nuisance dusts are applicable. At present, the Mine Safety and Health Administration (MSHA) dust standard is 5 mg/m^3 respirable and 10 mg/m^3 total, while the Occupational Safety and Health Administration (OSHA) dust standard is 5 mg/m^3 respirable and 15 mg/m^3 total (Zumwalde 1977). Both OSHA and MSHA limits are enforceable. In general, respirable dust levels were below 5 mg/m^3, but many of the total dust samples exceeded the 10mg/m^3 and 15 mg/m^3 standards. The highest dust levels were experienced by the mill operators, the screen operator, the bagging operators, and the shipper.

Selected airborne samples collected at various locations within the mill were analyzed by transmission electron microscopy. The morphology of the particulates was similar on all samples, with individual clay fibers being

Table 1. NIOSH Monitoring of Engelhard Minerals and Chemicals Corporation: Summary of Time-Weighted Average Exposures by Job Title

Job Title	Dust Concentrations[a] (Attapulgite) Respirable Mass (mg/m^3)	Total Mass (mg/m^3)
Stationary Samples (Milling Operations)	9.90*	15.94
Crane Operator	0.16	0.52
Hammer Mill Operator	0.41	0.46*
Pugmill Operator	1.40	6.45
Dryer Operator	0.57	--
Dryer Oiler	0.74	6.57*
Crusher Oiler	0.52	1.90*
Miller No. 1	1.15	21.47*
Miller No. 2	2.10	15.54*
Raymond Miller	1.42*	9.12*
Screen Operator	3.24	22.34
Stationary Samples (Bagging Operations)	2.04	12.62
Lead Person	1.01	9.78*
Shipper	1.72	16.30
Laborer	1.90	22.51
Bag Press Operator	0.72*	

NOTE: (*) Represents one sample
(--) No sample collected

[a] Samples for airborne respirable and total dust were collected at a flow rate of 1.7 liters per minute on 37 mm diameter pre-weighed MSA Type FWS (polyvinyl chloride) filters. Total dust samples were collected open faced; the respirable dust fractions were separated from the total dust using a 10 mm nylon cyclone separator. The samples were analyzed by gravimetric methods, and the results represent arithmetic means of multiple samples.

Source: Zumwalde 1977.

more numerous on samples collected near the dryers and the Raymond mills (Zumwalde 1977).

Electron microscopy data on the size of attapulgite fibers found at the Engelhard plant showed the average fiber to be 0.4 µm in length and 0.07 µm in diameter. The lengths ranged from 0.1 µm to 2.5 µm, while the diameter range was 0.02-0.1 µm. There appeared to be an affinity for fiber conglomeration into jagged particulates that ranged in diameter from 0.5 to 5.0 µm (Zumwalde 1977). Airborne fibers are generally of a respirable size (see Table 2).

Table 3 is a compilation of exposure data collected by MSHA for the major attapulgite mining and processing companies; the data include respirable dust and quartz levels. At Floridin, all workers and stations examined had respirable dust levels below the suggested exposure limit of 5 mg/m^3. At Oil-Dri, a dryer operator, dry screening operator, and a cleanup man all had more exposure to respirable quartz than is recommended. The dryer operator was exposed to 6.5 mg/m^3 of respirable quartz compared to the 1 mg/m^3 recommended standard. At Engelhard, the bagging operations workers exposed to the highest level of respirable quartz compared to the other plants. One sample showed a bagging worker's exposure level to be above the recommended exposure limit, 4.96 mg/m^3 compared to a recommended 2.68 mg/m^3. All of Milwhite's and Waverly's workers were exposed to concentrations of quartz that were below the recommended exposure limits. Quartz exposure limits depend upon quartz concentrations and, therefore, vary for each sample.

B. <u>Fiber Use</u>

Engelhard lists the Friction Division Products Company, Inc. and the Ford Motor Company as users of its attapulgite-based asbestos friction material substitute, EMCOR® 66. The report goes on to say that Schenectady

Table 2. Engelhard Minerals and Chemicals Corporation: Summary of Airborne Attapulgite Fiber Size Data as Determined by Electron Microscopy[a]

Fiber Measured	Count Median Micrometer (μm)	Range Micrometer (μm)	Geometric Standard Deviation
Diameter	0.07	0.02-0.1	3.14
Length	0.4	0.1-2.5	3.0

[a] Airborne samples collected at various locations within the mill were analyzed by transmission electron microscopy (TEM). Fiber diameter and length were determined at 20,000 X magnification.

Source: Zumwalde 1977.

Table 3. Mine Safety and Health Association Monitoring Results for Attapulgite

Plant/Mine Name	Date	Sample Location	Job	Respirable Concentration (mg/m^3)	MSHA Recommended Exposure Limit[a] (mg/m^3)
		EXPOSURE TO NUISANCE DUST, RESPIRABLE FRACTION			
Floridin	04/09/85	Mill -- Crushing	Crusher, Pan-Feeder Operators	0.17	5.00
	04/09/85	Surface -- Roads	Bulldozer Operator	0.68	5.00
	04/09/85	Surface Rods	Front End Loader Operator	0.13	5.00
	04/09/85	Mill -- Bagging	Bagging Operations Worker	0.32	5.00
	09/15/83	Surface-Active Mining	Bagging Operations Worker	0.28-0.83	5.00
		EXPOSURE TO RESPIRABLE DUST NOT ANALYZED OR BELOW DETECTION LIMIT (Exposure Limit 0.00)			
Floridin	01/18/84	Mill -- Bagging	Bagging Operation Worker	0.07-0.11	
		EXPOSURE TO QUARTZ, RESPIRABLE FRACTION, >1% QUARTZ			
Oil-Dri	03/14/84	Mill -- General (a number of areas)	Hand Loader	1.08	2.48
	03/14/84	Mill -- Drying	Dryer Operator	0.37	2.76
	05/26/83	Mill -- Drying	Dryer Operator	0.34	2.05
	12/12/84	Mill -- Drying	Dryer Operator	6.52	1.01
	03/14/84	Mill -- Dry Screening	Dry Screening Plant Operator	1.66	2.88
	05/26/83	Mill -- Dry Screening	Dry Screening Plant Operator	0.32	1.09
	12/12/84	Mill -- Dry Screening	Dry Screening Plant Operator	2.69	2.27
	05/26/83	Mill -- General	Cleanup Man	0.40	0.36
	12/12/84	Mill -- Bagging	Bagging Operations Worker	0.30-1.19	1.58-2.07
	03/14/84	Mill -- Bagging	Bagging Operations Worker	0.69	2.22-2.54
	05/26/83	Mill -- Bagging	Bagging Operations Worker	0.36-0.50	0.83-1.31
		EXPOSURE TO NUISANCE DUST, RESPIRABLE FRACTION, <1% QUARTZ			
Engelhard	01/13/84	Mill -- Bagging	Bagging Operations Worker	0.52	5.00
	03/13/85	Mill -- Bagging	Bagging Operations Worker	3.17	5.00

Table 3 (Continued)

Plant/Mine Name	Date	Sample Location	Job	Respirable Concentration (mg/m^3)	MSHA Recommended Exposure Limit[a] (mg/m^3)
			EXPOSURE TO QUARTZ, RESPIRABLE FRACTION, >1% QUARTZ		
Engelhard	04/14/83	Mill -- Dry Screening	Dry Screening Plant Operator	1.01	2.54
	04/14/83	Mill -- Bagging	Bagging Operations Worker	0.31	1.26
	04/14/83	Mill -- Bagging	Bagging Operations Worker	1.06	2.33
	03/13/85	Mill -- Bagging	Bagging Operations Worker	1.36	2.51
	01/13/84	Mill -- Bagging	Bagging Operations Worker	2.11	3.22
	01/13/84	Mill -- Bagging	Bagging Operations Worker	1.99	2.93
	03/13/84	Mill -- Bagging	Bagging Operations Worker	2.03	2.59
	01/13/84	Mill -- Bagging	Bagging Operations Worker	2.90	3.18
	04/14/83	Mill -- Bagging	Bagging Operations Worker	4.96	2.68
			EXPOSURE TO QUARTZ, RESPIRABLE FRACTION, >1% QUARTZ		
Milwhite	04/05/84	Mill -- Grinding	Ball, Rod, or Pebble Mill Operator	1.32	3.01
	10/17/84	Mill -- Drying	Hammer Mill Operator	0.50	2.38
	10/17/84	Mill -- Bagging	Dryer Operator	0.86	2.63
	10/17/84	Mill -- Bagging	Fortlift Operator	0.75	2.17
	10/17/84	Mill -- Bagging	Bagging Plant Operator	0.72	1.92
	04/05/84	Mill -- Bagging	Bagging Plant Operator	1.95	3.13
	05/05/84	Mill -- Bagging	Bagging Plant Operator	1.78	2.64
			EXPOSURE TO QUARTZ, RESPIRABLE FRACTION, >1% QUARTZ		
Waverly	01/08/85	Mill -- Bagging	Bagging Plant Operator	0.24	2.23
	01/08/85	Mill -- Bagging	Bagging Plant Operator	0.27	2.15
	06/30/83	Mill -- Bagging	Bagging Plant Operator	0.19	1.20
	06/30/83	Mill -- Bagging	Bagging Plant Operator	0.14	0.83
	01/08/85	Mill -- Bagging	Bagging Plant Operator	0.19	1.03
	01/08/85	Mill -- Bagging	Bagging Plant Operator	0.36	1.87

[a] Exposure limit depends upon quartz concentration.

Source: MSHA 1986.

Chemicals, Inc., a friction resins supplier, recommends EMCOR® 66 to its customers (Engelhard Minerals and Chemicals 1985).

Floridin supplies attapulgite to approximately 1,000 different companies including Monsanto, U.S. Gypsum, Exxon, Ciba-Geigy, Excel Minerals, and Stauffer (Floridin 1986a). Engelhard sells their attapulgite to Union Carbide, United Catalysts, Monsanto, Stauffer, Rhone-Poulenc, Ciba-Geigy, and American Cyanimid; the list continues and is quite extensive (Engelhard Specialty Chemicals 1986a).

Milwhite refused to disclose the names of the firms to whom it supplies attapulgite, but guessed that it shipped directly to 50-100 other companies. Each of their buyers has its own clients, and the number of companies that Milwhite supplies indirectly greatly exceeds one hundred.

Both Floridin and Engelhard state that they sell only finished, processed attapulgite. They never release unprocessed, crude material. Sometimes additives are combined with the attapulgite by the buyer, but that is the full extent of processing that the purchaser must undergo (Floridin 1986a, Engelhard Specialty Chemicals 1986a). Milwhite, however, does sell attapulgite in its raw state to customers who prefer to process it themselves. This attapulgite is shipped in a semi-dry state or straight out of the ground (Milwhite 1986a).

Table 4 presents a breakdown of the variety and uses of attapulgite by trade name and producer.

Table 5 lists the major uses of each grade (coarse/absorbent, fine, and gelling) of attapulgite. The first two grades (coarse/absorbent and fine) constitute the non-gelling variety of attapulgite. Each grade has specific applications, although some uses overlap between coarse and fine grades of attapulgite.

Table 4. Common Trade Names of Attapulgite and Uses

Name of Company	Trade Name	Variety of Attapulgite	Use
Floridin Company	Florex	Non-gellant[a]	Agricultural pesticide carriers Industrial oil and grease absorbents Pet litter Refining clays for the clarification of jet fuel
	Min-u-gel Florigel H-Y	Gellant	Oil drilling muds Suspension fertilizers Catalysts Asbestos replacement in asphalt and friction materials Joint cement compounds Dry wall material
Engelhard Corporation	Attasorb	Non-gellant	Pet litter Agricultural pesticide carriers Oil and grease absorbents
	Attapulgus 150	Gellant	Oil drilling muds
	Attapulgus 350 and 390	Gellant	Agricultural fluid suspension fertilizers
	Pharmasorb	Gellant	Pharmaceuticals
	Emcor 66	Gellant	Asbestos-replacement friction material Liquid animal food supplements Cleaning surfactants for jet fuels and oils Paraffin manufacture Petroleum jelly manufacture Paint thickener Tape joints Roof coatings

Table 4 (Continued)

Name of Company	Trade Name	Variety of Attapulgite	Use
Milwhite Company	Gel B	Gellant	Paints and joint cements
	Fert-o-Gel	Gellant	Suspension fertilizers
	Basco	Gellant	Salt-water drilling mud
	-	Non-gellant	Pet litter Oil refining clays
Oil-Dri Corp. of America	-	Non-gellant	Oil absorbents Pet litter Agricultural pesticide carriers Flow agent in animal feeds
Waverly Mineral Products	-	Non-gellant	-

[a] Non-gellant category includes coarse/absorbent and fine grades.

Sources: Industrial Minerals 1985, Floridin 1986a, Engelhard Specialty Chemicals 1986a, Milwhite 1986a.

Table 5. Commercial Uses of Attapulgite

Type of Attapulgite	Major Product Uses
Coarse absorbent grade (non-gelling)	• Litter and beddings for poultry, pets, and other animals. • Oil and grease absorbents in factories, on decks and in engine rooms of ships, and in other industrial installations.
Fine absorbent grade (non-gelling)	• Substances for filtering, clarifying, and decolorizing mineral oils and greases. • Base material (called carrier) for insecticides and fungicides. • As fillers for: -- paints -- paper -- rubber -- adhesives
Highly refined gellant	• Salt-water drilling muds. • Agricultural fluid suspension fertilizers. • Pharmaceuticals. • Catalysts. • Asbestos-replacement friction materials.

Course or granular grades are generally used for most applications requiring good absorbency. Finer grades, made by further processing coarse-grade attapulgite to decrease the moisture content and particle size, are used for refining mineral oils; for making pesticides; for use as filler in paints; and in adhesives, rubber compounds, and paper products. Gellant grades of attapulgite, made by processing fine grades in fluid energy mills to get extremely fine particles with good suspension characteristics, are used as salt-water drilling muds, as agricultural suspensions, as catalysts for certain organic processes, and as asbestos-replacement friction materials (ICF 1986).

The potential for exposure during the manufacture of the two major attapulgite products, oil and grease absorbents/pet litter and agricultural carriers, is presented in detail below.

1. Oil and Grease Absorbents/Pet Litter

Coarse grade attapulgite granules are very dry and porous. Capillary action pulls liquids like oils or animal wastes into the granule and holds them there.

a. Manufacturers

Industrial absorbent grade attapulgite (630 mesh grade) is bagged under private client names at the Floridin Co. plants or is sold under the Floridin trade names: Florco, Florco-X, Flor-Kleen, and Cal-Flor-Dri. Pet litter products are not sold under Floridin trade names. Floridin sells clay for this purpose to other companies for repackaging (Floridin 1986b).

The product Flocol-X is used as pet litter, a jet engine refining clay, as well as an oil and grease absorbent. Pet litter manufacturers like Superior Pet buy the clay and reprocess it by adding their own perfumes. The portions of this product used as oil and grease absorbents and jet fuel refining clays require no further processing than what is done at the Floridin plant (Floridin 1986c).

The Engelhard Corporation markets its attapulgite pet litter under its own name and packages it for other companies under the names of those companies. Engelhard's own labels include the brands Poise, an unscented product, and Fragran, a scented pet litter. Other company names under which Engelhard bags its clay include A&P and Food Town. Engelhard, like Floridin, sells its clay in bulk to repackagers who have their own bag-packing equipment. These companies include International Packaging Incorporated, Orlando, FL; Superior Pet, Quincy, MA; and Excel Mineral (Engelhard Specialty Chemicals 1986c).

All of Engelhard's oil and grease absorbent clay is sold to International Packaging; G.M. Gannon, Cranston, RI; and Dri-Rite, Blue Island, IL. These companies repackage the clay under other names. No further processing is done (Engelhard Specialty Chemicals 1986c).

The Oil-Dri Corporation of America makes four oil and grease absorbents under the Oil-Dri brand name. They also manufacture kitty litter under their trade name, Kitty-Dri. These products may also be packaged under other, private labels for clients. Oil-Dri does not sell to repackagers (Oil-Dri 1986).

Information on the total number of repackagers was not available.

b. Manufacturing Process/Potential Exposure Points

Mining and processing techniques at Floridin, Engelhard, and Oil-Dri are discussed in the Section A, Fiber Production. The processing at these plants results in finished products; the oil and grease absorbents and pet litter manufacturing processes at these companies do not go beyond the bagging stage described previously. The potential exposure points have been examined as well. It is only when attapulgite producers sell their products to outside firms for further modification and repackaging that further exposure may occur.

International Packaging is an example of an outside firm where exposure to attapulgite is possible during the bagging of oil and grease absorbents and animal litter. International Packaging does not process the clay at all, but merely bags it. Attapulgite is delivered to International Packaging in hopper cars and trucks. Gravity flow chutes unload the clay onto conveyers which take it to fully enclosed bulk tanks. From the bulk tanks, the clay is fed into a storage tank and proceeds to the packer from there. In the packer, clay is blown into bags which are loaded into a magazine. Filled bags are palletized and shipped to a feed store. The packaging lines are automated to some extent, but still require the presence of operators.

Pet owners and breeders do not wear any dust protection when handling the litter.

International Packaging packs attapulgite into 5, 10, 25, and 50-pound bags. The first three sizes are used ultimately for pets by homeowners. Breeders buy the 25 and 50-pound sizes for larger domestic animals like cattle. Machines sew the bags shut, hence exposure is not a problem for retailers of animal litter like feed store operators. International Packaging does not sell the clay on a retail basis.

Oil and grease absorbents are available in 40 and 50-pound bags. Absorbents are packaged using the very same techniques and machinery used for bagging pet litter. International Packaging sells the absorbent to auto parts stores and industrial supply stores (International Packaging 1986).

All of the packaging equipment is enclosed, and a dust control system removes dust from the air near the tanks and the packers. If employees are exposed to dust, masks are provided for their protection (International Packaging 1986).

c. Extent of Potential Exposure

The number of persons exposed to attapulgite, the duration of exposure, and the respirability of the airborne fibers for the attapulgite producers/manufacturers (Floridin, Engelhard, and Milwhite) discussed in Section A.3.

International Packaging requires two to three people to operate a packing line. A typical plant has two or three packing lines. International Packaging maintains several packaging plants. The Dri-Rite Company in Blue Island, IL is a subcontractor for International Packaging and occasionally does packaging for them (International Packaging 1986).

Beyond the producer/manufacturer plants, oil and grease absorbents are sold to and distributed by auto supply and mill supply distribution houses. No exposure occurs until the bag is opened. An MSDS goes along with these products recommending that dust masks be worn if workers are to be in contact with large amounts of the material (Floridin 1986b).

2. Agricultural Carriers

a. Manufacturers

Attapulgite clay is used extensively in the agricultural industry -- mostly as a carrier for pesticides, herbicides, and insecticides. Homeowners' yard products also frequently contain attapulgite.

One of Floridin's largest selling products is a pesticide carrier called Florex (Floridin 1986c). Oil-Dri sells bulk shipments of attapulgite for agricultural compound carriers under the name Ag-Sorb (Oil Dri 1986). Rhone-Poulenc, Inc. contracts out the mixing of its herbicide, Rorstar, with attapulgite carriers to Agway of York, PA; Farmland in Joseph, MO; and Coastal

Chemical in Kinstol, NC; they do not handle the attapulgite themselves (Rhone-Poulenc 1986). At Stauffer Chemical Company (hereafter referred to as Stauffer), the Agricultural Chemical Division uses attapulgite as a granular carrier for pesticides (Stauffer 1986).

At Monsanto Company, four granular herbicide formulations contain attapulgite clay; these are: Fargo, Avadex, Ramrod, and Lasso II (Monsanto 1986). These herbicides control wild oat infestations in barley and wheat as well as the weeds affecting corn, soybeans, milo, peanuts, cotton, potatoes, and ornamentals (Monsanto 1983). Ciba-Geigy Corporation also uses attapulgite as a carrier for some of its pesticide products (Ciba-Geigy 1986).

b. Manufacturing Process/Potential Exposure Points

The attapulgite is used as an agricultural carrier in three ways:

- Granular formulations -- This is the most common use for attapulgite. The clay is impregnated with a chemical compound by spraying. If the chemical is not readily soluble in normal solvents, an adhesive is added to stick the chemical onto the clay.
- Wettable Dispersible Granules -- These granules serve to carry wettable powder chemicals like the organophosphates. Kaolin is preferred in these applications over attapulgite.
- Suspended Clay in Water -- This medium is used for suspension fertilizers and other flowable types of formulations (Ciba-Geigy 1986).

At Ciba-Geigy the clay comes to the plant either in bags or in 70 ton hopper cars. Doors open under the hopper car, and the material flows through a chute into a silo. If clay is delivered in bags, employees must manually cut them open and empty them into the silo. The material is taken into the plant on a conveyer. Along the conveyer route, the clay is screened, and particles smaller than 60 mesh grade are removed and discarded; this greatly reduces airborne dust. Greater than 60 mesh grade material is fed into an enclosed blender and sprayed with the compounds to be carried. After spraying, dust is virtually eliminated, and the clay impregnated with chemicals is packaged for shipment. The workers wear dust masks when unloading the hopper cars. Any cutting of bags and clay handling is done inside the plant close enough to chemical spraying so that workers wear breathing protection anyway. Ciba-Geigy occasionally subcontracts work out to Farmland and Agway (Ciga-Geigy 1986).

Stauffer Chemical uses attapulgite granules to carry its Dyfonate 10-G and 20-G insecticides. At Stauffer, the exposure to attapulgite is minimal because all production is enclosed and automated including the entire bagging operation. All unloading and loading of clay is completely automated in silos. The worker who operates the production line stands in an enclosed glass control room. Workers who handle filled bags of the finished product wear dust masks. The only other exposures that are likely to occur are during clean-out operations or during product testing in the lab (Stauffer Chemical 1986a). Stauffer does not subcontract any of this chemical carrier work.

Shipments of these agricultural products come with product safety instruction sheets that explain safe handling procedures to the farmers who will have contact with them during their end use. The Dyfonate 10-G sheet states that in the event of a spill a positive pressure, self-contained breathing device or positive-pressure supplied air respirator with escape pack should be employed. Swept up wastes should be placed in chemical waste containers. The floor should be washed and rinsed carefully. Stauffer recommends evacuating the area in which Dyfonate 20-G has been spilled. RCRA governs disposal of this material. Clearly exposure to the clay is much less dangerous than exposure to the insecticide, and precautions taken in pesticide handling are more than adequate for clay exposure (Stauffer Chemical 1986b, 1986c).

Monsanto buys attapulgite clay from both Floridin and Engelhard for use as herbicide carriers. The clay arrives at Monsanto's Muskatine, Iowa plant in rail cars where it is bottom unloaded. A motor driven system opens the gate in the rail car's floor, allowing the clay to flow by gravity into a pit below the tracks. In the pit, a belt conveyer takes the clay to a bucket elevator which dumps the material into a silo system. From the silo, the clay is screened to be sure that only the appropriate sized granules will actually make it into the weigh hopper. The contents of the weigh hopper is transported to the mix vessel where a premeasured amount of herbicide is added by spraying. The mix vessel blends the clay and herbicide. The material is screened once again before being loaded into 50-pound bags (Monsanto 1986).

Engineering controls exist throughout the Monsanto plant for dust control. The conveyer for unloading the clay is enclosed and has a vacuum system which removes dust to a baghouse. This enclosed vacuum and baghouse system is also present on the other equipment including the bucket elevators, screens, mixers, and bagging machinery. The screens before and after the mix vessel remove fine dust as well as oversize materials thus reducing the airborne dust levels greatly. The fines and dust collected at the screen and baghouses before the mix vessel are disposed of in a sanitary landfill, while those contaminated fines collected after mixing with the herbicide must be disposed of in hazardous waste sites. The workers do not wear personal protection equipment because the dust level is found to be very low by continued testing (Monsanto 1986); however, no monitoring data have been provided.

c. Extent of Potential Exposure

Two or three people can unload a hopper car. The number of shifts per day varies. The October to January season is very busy. As the material is manufactured, it is shipped out rapidly. The chemical in the mixture is in low concentration, and storage is uneconomical because of the high volume of clay carrier to be stored (Ciba-Geigy 1986).

The Monsanto plant operates seven days a week, 24 hours per day. Four shifts work the line each day, with at least two men on each shift. One operator runs the control panel which is separated from the plant interior by a fire wall. Another worker is responsible for taking samples. Two workers run the bagging machine which makes use of a surge hopper and is, therefore, run only five days per week (Monsanto 1986).

3. Oil Drilling Muds/Jet Fuel Cleaners

The Attapulgus 150 brand drilling clay from Engelhard is sold directly to companies that perform the drilling; no further processing is necessary. The drillers measure the clay directly into their batches from the 50-pound bags. In contrast, the clay sold for drilling muds by Floridin is sold to buyers who make their own mixes and then resell the finished mud (Floridin 1986c). The jet fuel cleaners are also a granular finished product. Refineries, airports, and pipeline transmission companies purchase this product to remove surfactants from fuel (Englehard Specialty Chemicals 1986c).

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IV. CARBON/GRAPHITE FIBERS

Carbon/graphite fibers are filamentary forms of carbon produced by high temperature processing of one of three precursor materials: rayon (regenerated cellulose), pitch (coal tar or petroleum residue), or polyacrylonitrile (specialty acrylic fiber, PAN). The terms "carbon" and "graphite" are often used interchangeably when referring to fibers; however, differences do exist. Graphite fibers, because of their three dimensional polycrystalline nature, tend to be stronger and stiffer than carbon fibers. Also, graphite fibers generally require higher temperatures for production. The strength of the carbon/graphite fiber depends on both the molecular orientation and purity of the precursor, while the processing temperature of the fiber determines the Young's modulus. The typical temperature range for graphite fiber production is between 3500°F and 5400°F, while carbon fiber is manufactured at about 2400°F. Eighty-five percent of all carbon/graphite fibers are of the graphite type (ICF Inc. 1986).

Carbon/graphite fibers are used in advanced composite materials. Embedded in a matrix such as a polymer, carbon/graphite fibers can improve the strength, stiffness, and/or the durability of the composite material. They may also be used to impart other characteristics to the composite material such as better electrical conductivity or greater wear resistance.

Fibers are available in diameters ranging from 5 μm to greater than 8 μm in diameter. The most common fiber diameter appears to be 7-8 μm. Fibers intended for specialty uses may be smaller in diameter, 5-5.3 μm.

A. Fiber Production

1. Fiber Producers

There are 11 manufacturers of carbon/graphite fiber producing at 23 plants in the United States. The largest of these firms are Hercules

Aerospace (hereafter referred to as Hercules) (PAN-based fibers only), Union Carbide/Amoco Specialty Polymers and Composite Division (hereafter referred to as Union Carbide/Amoco)* (PAN, pitch, and rayon-based fibers), and Celion Carbon Fibers, Division of BASF Structural Materials (hereafter referred to as CCF/BASF) (PAN-based fibers only) (U.S. DOC/ITA 1985). Table 1 identifies all eleven manufacturers, precursors used, production capacity, and their product trade names. These firms are arranged by the type of precursor material(s) they use to manufacture their carbon/graphite fibers. The most common precursor materials are polyacrylonitrile (PAN), purchased as such or produced in-house by polymerizing acrylonitrile; pitch, obtained from the petrochemical industry; and rayon, purchased as such from textile fiber manufacturers. The type of precursor used will affect the fibers final properties including Young's modulus, tensile strength, and cost (ICF Inc. 1986).

The principal producers of carbon/graphite fibers are Japan, the United States, and the United Kingdom. Japan is the leading manufacturer of carbon/graphite fiber. Its industry is centered on the production of PAN-based fibers, drawing upon the excess acrylic fiber capacity of the Japanese petrochemical industry. The United States' capabilities in both PAN technology and production of carbon/graphite fiber from PAN ranks second to Japan. However, the U.S. has done the most work in developing carbon/graphite fibers based on the precursors rayon and pitch, leading the world in production of carbon/graphite fiber based on these two materials. Furthermore, American firms are overshadowing the rest of the world in the development and application of composite materials incorporating

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* Calls made prior to June 20, 1986 will be referenced as "Union Carbide 1986."

Table 1. Producers of Carbon/Graphite Fibers

Carbon/ Graphite Fiber Type	Producer	Trade Name	Production Capacity[a] (lbs.)
Rayon-Base	Polycarbon Inc.	-	300,000
	Union Carbide/Amoco[b]	WCA®	250,000
	HITCO	CCA-4®	208,000
PAN-Base	Hercules Aerospace	Magnamite®	1,300,000
	Union Carbide/Amoco[b]	Thornel-T®	800,000
	CCF/BASF[c]	Celion®	300,000
	Stackpole Fibers Co.	Panex®	180,000
	AVCO Specialty Materials Inc.	-	150,000[d]
	HITCO	HITEX®	200,000
	Great Lakes Carbon Corp.	Fortafil®	50,000
	Fiber Materials Inc.	-	4,000
	Hysol/Corafil	-	N/D
Pitch-Base	Union Carbide/Amoco[b]	Thornel-P®	1,000,000
	Ashland Petroleum Company	Carboflex™	200,000

N/D -- No data.

[a] 1982.

[b] Union Carbide's carbon fiber production facilities were sold to Amoco effective June 20, 1986. (Union Carbide/Amoco 1986)

[c] Formerly Celanese.

[d] Capacity is now ~30,000 lbs (AVCO 1986).

Sources: U.S. DOC/ITA 1985, Ashland Petroleum Company 1985.

carbon/graphite fibers. PAN is presently the world's dominant precursor used for the production of carbon/graphite fiber and is expected to continue as such in the immediate future; however, some Japanese firms are making strenuous efforts to make greater use of lower-priced pitch as a precursor material (ICF Inc. 1986).

2. Fiber Production Process/Potential Exposure Points

a. Process Description and Automation

(1) Overview

Carbon/graphite fiber products are produced using the same generic process regardless of the precursor or final product. The initial precursors (PAN, pitch, or rayon) are oxidatively stabilized and dehydrated at moderate temperatures (400-600°F). Following this step, the fiber is carbonized at a temperature of 1400-2500°F in a non-oxidizing atmosphere and then undergoes graphitization at 2600°F+, under an inert atmosphere (U.S. DOC/ITA 1985). Depending on the configuration of the final product (e.g. chopped fiber, continuous strand, felt, fabric) and intended usage, the fiber may be treated with a sizing material or packaged and shipped directly. The manufacturing process is usually conducted with significant automation (i.e., minimum manual materials handling). From this basic process, different manufacturers have introduced variants to enable more efficient production of their specific products.

Process specific information on the manufacture of carbon/graphite fibers is limited by the very competitive nature of the industry. Most manufacturers declined to discuss process specifics with ICF but were willing to provide limited generic information about various processes. Figure 1 presents a flow diagram for the production of carbon/graphite fibers.

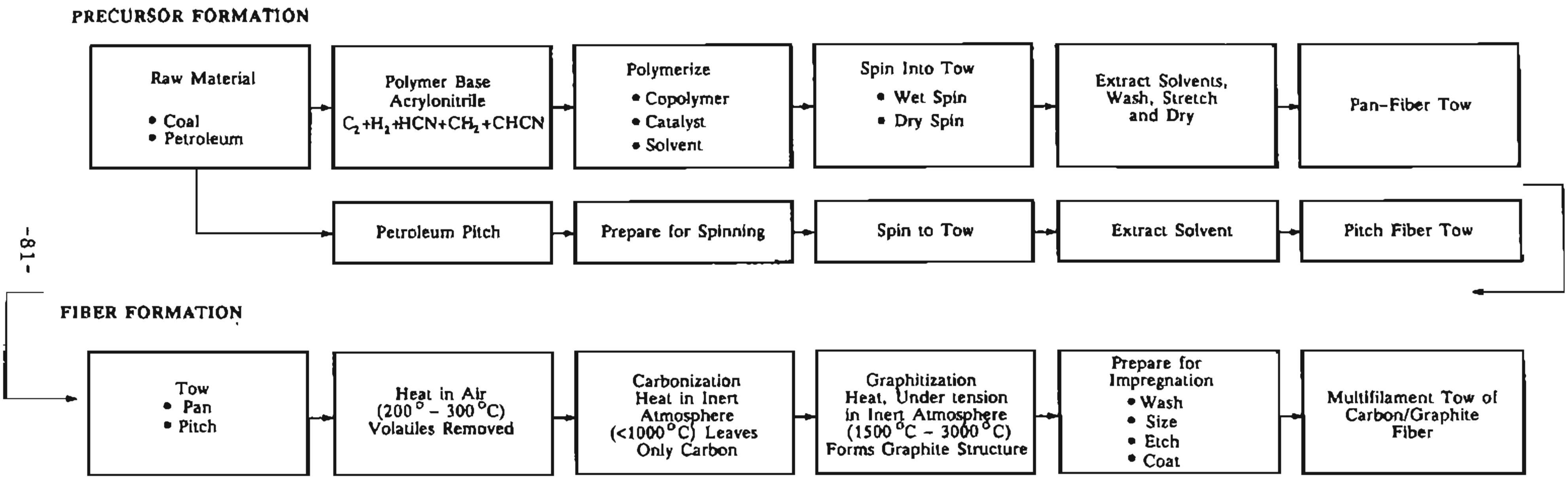

Figure 1. Carbon/graphite fiber production process. (Source: Zumwalde 1980.)

(2) Precursors

Carbon/graphite fiber precursors may either be purchased in filament form or spun in plant in preparation for pyrolysis and carbonization. Most manufacturers indicate that for PAN based carbon/graphite fiber, the common practice is to purchase PAN (acrylic fiber, such as Orlon™) as a continuous filament in large cartons. Typically, the PAN is purchased as a white fiber (i.e., with no sizing materials such as dye receptors). One manufacturer, Union Carbide/Amoco, indicated that they polymerized acrylonitrile themselves to create PAN, rather than purchasing the material (Union Carbide 1986a).

Union Carbide/Amoco, the only U.S. manufacturer to produce carbon/graphite fibers from all three precursors, indicated that pitch for their process was supplied in heated tank cars and was transformed using a proprietary process to a form suitable for pyrolysis (Union Carbide 1986b). There are two processes used to produce pitch fibers. In the first process, the pitch is spun from a melt and then thermoset at low temperatures for a long period of time. The second process differs from the first in that the pitch first passes through a heat treatment phase in order to transform it into a liquid-crystalline (mesophase) state. The pitch is then spun and thermoset (Lubin 1982).

Rayon, as a precursor, arrives in plant as a filament, yarn, or fabric ready for pyrolysis (Union Carbide 1986b). Rayon is spun and then treated in a low temperature atmosphere prior to carbonization. This low temperature heat treatment is designed to stabilize the fibers for subsequent carbonization by converting the rayon to a char (Lubin 1982).

The form that the precursor arrives in may vary depending on the desired carbon/graphite fiber product. Products such as yarns, fabrics, and felts, that require significant amounts of handling (e.g., weaving, spinning, or needlepunching) are usually best produced as such from the precursor and then carbonized. This is due in large part to the high Young's modulus (the higher the modulus a fiber displays, the less flexible it is) that carbon/graphite fibers display. An example of this may be found in Polycarbon's felt production. Rather than needlepunch finished carbon/graphite fibers to create a felt, they purchase the precursor in felt form. Precursors for continuous carbon/graphite fibers are typically arranged in strands of 3000, 6000, or 12,000 filaments prior to processing (Polycarbon Inc. 1986).

(3) <u>Initial Oxidation</u>

All manufacturers contacted by ICF indicate that precursor materials are initially oxidized at moderate temperatures. Immediately prior to the initial oxidation, PAN precursor filaments are steamed and stretched to align the fibrillar networks within each fiber parallel to the fiber axis, and then dried (Lubin 1982, Great Lakes Carbon Corp. 1986b). Oxidation serves to change the nature of the fiber by adding oxygen to the basic structure and will prevent the fiber (PAN) from melting in subsequent heatings. This is the rate determining step in the carbon/graphite fiber production process as it is the longest in duration (Great Lakes Carbon Corp. 1986b). One manufacturer, Union Carbide/Amoco, indicated that their fibers undergo this initial step for 20 minutes to 2 hours, depending on the fiber properties desired (Union Carbide 1986a). Another manufacturer indicated that their fiber is oxidized initially for approximately two weeks (Polycarbon 1986). In the case of PAN fibers, the rate of oxidation appears to be controlled by the rate of diffusion of oxygen to the center of the fiber (Lubin 1982). During this stage, there is very little weight change in the fiber (Great Lakes Carbon Corp. 1986b).

Initial oxidation of precursors may be conducted as a batch operation, discontinuous from the rest of the production line, due to its prolonged nature. In such cases, the strands are wound onto bobbins and transferred manually to the carbonization area for further processing.

(4) Carbonization

Once the fiber has been subject to the initial oxidation step, it is then carbonized (pyrolyzed). Because the fiber has relatively low Young's modulus at the beginning of this step, operations such as weaving or yarn spinning may be better conducted prior to carbonization. Most manufacturers indicate that this step is continuous in nature. Fiber is drawn by rollers through a series of furnaces heated from 1400°F to 2500°F to gradually improve its characteristics and properties. Materials, such as fabrics, may be run batchwise in furnaces. This process is usually carried out under an inert atmosphere to prevent inadvertent combustion of the fiber. At this stage, most, if not all, non-carbon elements are driven from the precursor fiber (Lubin 1982).

By-products of pyrolysis (e.g., hydrogen cyanide from PAN-based fibers, and polynuclear aromatics (PNAs) from pitch-based fibers) are captured and incinerated prior to release. One manufacturer indicated that as much as 25 percent of the original weight of the fiber may be driven off in this heating (Great Lakes Carbon Corp. 1986b).

(5) Graphitization

After initial carbonization, fibers may proceed to a secondary heating phase known as graphitization. In a continuous process, strands are conducted through consecutive ovens using rollers and drivers. In this stage, the fibers are reheated to greater than 2,600°F in order to change their crystalline structure to a more graphitic nature. Great Lakes Carbon

Corporation indicated that as much as another 25 percent of the original fiber weight is driven off in this step (Great Lakes Carbon Corp. 1986b). Some by-products found include ammonia, cyanide, and hydrocarbons; these materials are decomposed in the heating process (Union Carbide 1986c).

(6) Finishing

Once the carbon/graphite fiber has achieved desired properties, it may proceed to a finishing area. At this operation, it may be coated with various materials to improve its handling characteristics and compatibility with various matrices (Union Carbide 1986a). This process of surface coating fibers with various materials is known as "sizing". Only one carbon/graphite fiber manufacturer, a producer of fiber exclusively for the manufacture of carbon-carbon aircraft brakes, indicated that its product was shipped without sizing materials (AVCO Specialty Materials 1986).

Most manufacturers contacted by ICF indicated that sizing compound formulations were proprietary in nature. Two manufacturers, Union Carbide/Amoco and CCF/BASF, stated that sizing materials were typically compounds such as epoxy-based functionalities, resins, epoxides, and aqueous systems all designed to provide good handling properties and achieve good bonding between the fiber(s) and the matrix (Union Carbide 1986a, CCF/BASF 1986). These compounds are applied to fiber in baths at 1-5 percent concentration.

Once the sizing materials have been applied onto the fiber, the strand is conducted to a winding operation. Here, using standard textile industry machinery, the fiber is wound prior to shipment. Manufacturers differ in that some wind directly onto the bobbin to be supplied to the customer, while others wind onto large creels and then rewind onto bobbins as per customer orders. Once wound, bobbins are then manually transferred to a shrink wrap machine where they are sealed prior to packaging for shipment. Once wrapped, fiber exposure is expected to be minimal (Union Carbide 1986a). Secondary operations, such as chopping, are supported by bobbins or creels transferred off-line (Great Lakes Carbon Corp. 1986b).

Other carbon/graphite fiber products such as felt, fabric, and yarn may be rolled prior to shipment or shipped as is (i.e., in the same form it entered the furnace).

(7) Chopped Fiber

Two manufacturers, Great Lakes Carbon Corporation and CCF/BASF, indicated that a substantial portion of their fiber production (i.e., greater than or equal to 50 percent) was devoted to chopped fiber. Hercules Aerospace indicated that an unspecified portion of their production capacity was devoted to producing 0.25 inch chopped fiber (Hercules Aerospace 1986). Fibers are chopped to lengths from 0.125 to 1.0 inches in length for use in reinforced composite materials, or milled down to 200μm for specialty conductive applications (Great Lakes Carbon Corp. 1986b). The most common size is 0.25 inches.

Chopping operations are conducted off-line in a separate area of the facility. Typically, bobbins containing carbon/graphite fiber are manually transferred from the winding operation to the chopping area where they are fed into enclosed chopping machinery (CCF/BASF 1986). Negative pressure suction systems on the chopper draw fibers into containers for distribution (Great Lakes Carbon Corp. 1986b).

b. Engineering Controls and Protective Equipment

(1) Engineering Controls

The most preferable method for controlling carbon/graphite fiber and by-product exposures is through the use of engineering controls.

These may be supplemented through the use of personal protective equipment and administrative controls. The typical continuous carbon/graphite fiber production facility uses a combination of local exhaust ventilation, general dilution ventilation, and process enclosure to reduce worker exposure levels. In addition, the highly automated nature of most production facilities provides for minimal worker intervention.

Little data were available on the usage of administrative controls to minimize fiber exposures. Two manufacturers, Union Carbide/Amoco and Great Lakes Carbon Corporation, indicated that workers handled the fibers infrequently in situations such as strand breakage or to transfer full bobbins of fiber to shrink wrap machines for packaging (Union Carbide 1986c, Great Lakes Carbon Corp. 1986b).

In most continuous fiber production facilities, the strands are conveyed through the process using rollers and guides in a continuous flow (i.e., rather than batch processing). Because of this, very little handling is required for most areas. Some manual intervention may be required when the initial oxidation is conducted in a batch mode, and/or in transferring the finished fiber to another operation (e.g., chopping or packaging) (Union Carbide 1986a, Great Lakes Carbon Corp. 1986b).

The typical production facility uses local exhaust ducts near the beginning and end of each furnace to capture fibrous and pyrolysis by-product emissions. Some of this air may be recirculated to reduce heating demands for make up air. Typically, air exhausted from the furnace areas is incinerated due to presence of pyrolysis by-products such as cyanides and polyaromatic hydrocarbons (PAHs) (CCF/BASF 1986). Polycarbon Inc., a manufacturer of carbon fiber products such as yarns, fabric and felt, uses low velocity, high volume ventilation in the initial oxidation step and process enclosure and low velocity, low volume inert gas during carbonization and graphitization (Polycarbon 1986).

Once the strand has undergone carbonization and graphitization, it may proceed through sizing baths. Typically, sizing baths are closed systems with localized exhaust ventilation to capture emissions. Emissions of fibers should be minimal at this stage.

Emissions of carbon/graphite fibers and fly (i.e., the chaff that may separate from the fiber during handling) are usually minimal until the winding operations. Virtually all manufacturers cite winding operations as the most likely area for exposures to carbon/graphite fibers. Typically, local exhaust ventilation is used to capture as much material as possible. One manufacturer, CCF/BASF, cites the use of a low velocity, high volume laminar air flow room (downdraft airflow, i.e., air flows from ceiling to floor level) as a control methodology to minimize fiber exposure. Any recirculated air from this room must pass through high efficiency particulate filters prior to recirculation (CCF/BASF 1986). Hercules Aerospace cites the use of heavy coats of sizing materials as a means of preventing/minimizing carbon fiber fly (Hercules Aerospace 1986).

Chopping operations are typically conducted off-line, possibly in separate rooms with independent ventilation systems. One manufacturer, Great Lakes Carbon Corporation, indicated that a negative pressure suction system was in place on the chopping machinery to draw chopped fibers into containers for distribution and sale (Great Lakes Carbon Corp. 1986b). Another manufacturer, Hercules Aerospace, indicate the use of enclosed machinery, non-recirculating exhaust ventilation, and liberal application of sizing materials as some control methods in use (Hercules Aerospace 1986).

Carbon/graphite fibers and fly are highly conductive materials. For this reason, housekeeping is typically done with industrial vacuum cleaners and on a frequent basis. Mechanized floor sweepers may also be used in place of vacuum cleaners. Additional requirements, due to the conductive nature of the fibers, are pressurization, sealing, or explosion-proofing of any control or process electrical equipment to prevent inadvertent shorting. Due to their non-combustible nature, carbon/graphite fibers are typically landfilled and not incinerated (Union Carbide 1986a).

(2) Personal Protective Equipment

The typical manufacturing facility uses only minimal personal protective equipment for routine operations. This may include the use of company issued coveralls and gloves to protect against the contact dermatitis potential of the fibers. Some facilities issue disposable coveralls (Tyvek®) and dust masks for use by workers in actual contact with fibers (continuous and/or chopped) (Great Lakes Carbon Corp. 1986b). Other facilities cite no routine use of respirators or other personal protective equipment except in maintenance or emergency situations (Union Carbide 1986b, AVCO Specialty Materials Inc. 1986). One manufacturer, CCF/BASF, cites the use of personal protective equipment for use by individuals that display hypersensitivity to carbon/graphite fibers (Celion Carbon Fibers 1986). Another manufacturer, Hercules Aerospace, indicated that there is no routine use of personal protective equipment by plant personnel, including maintenance staffs, however, workers may were dust masks if they desire (Hercules Aerospace 1986).

3. Extent of Potential Exposure

a. Number of Persons Exposed

Quantifying the number of workers actually or potentially exposed to carbon/graphite fibers is a difficult task compounded by several factors. One reason is the automated nature of the manufacturing process. For example, CCF/BASF indicated that while their workers are assigned to carbon/graphite fiber production tasks, they may not be in areas subject to carbon/graphite fiber exposure at all times (CCF/BASF 1986). This type of discontinuous activity also makes it difficult to define the number of hours a worker is actually exposed. It is probable that workers assigned to the winding/packaging areas of the production line would be most likely to be exposed to airborne fibers. Unfortunately, no breakdown of personnel was available for this area. The number of workers potentially exposed in all areas, for the ten United States manufacturers, range from 10 at AVCO (AVCO Specialty Materials Inc. 1986) to 250 at Hercules Aerospace (Hercules Aerospace 1986).

b. Duration of Exposure

The typical production line worker does not appear to remain in the immediate vicinity of the line (i.e., exposed to carbon/graphite fibers) on a constant basis. Rather, it appears that these workers function in a reactive role; for example, splicing in a new strand or clearing a blockage in a furnace (Great Lakes Carbon Corp. 1986b). Because of the nature of the task and the insufficient data, it is not possible to indicate an average duration of exposure at this time.

The typical production facility is operated on a continuous basis with 24 hour operator coverage. Data on days/year of facility operation was considered proprietary by some manufacturers. However, two of the largest manufacturers, Hercules Aerospace and Union Carbide/Amoco, indicated that their plants were in operation 365 days/year (Hercules Aerospace 1986, Union Carbide 1986e). Union Carbide/Amoco also indicated that workers work 12 hour shifts (Union Carbide 1986d). Hercules Aerospace indicated that their workers are on 8 hour shift schedules (Hercules Aerospace 1986). Polycarbon, Inc. indicated that its workers work three 8 hour shifts, six days a week, and two 8 hour shifts on Sunday (Polycarbon 1986).

c. Respirability of Airborne Fibers

Exposure data for carbon/graphite fiber production facilities came largely from two sources (Dahlquist 1984, Gilliam 1986). Workers at the Great Lakes Carbon Corporation facility in Rockwood, TN demonstrated exposures ranging from 0.10 to 0.80 mg/m^3 when sampled as nuisance particulate (i.e., by mass) (Gilliam 1986). A total of six breathing zone samples were collected and analyzed; the results are shown in Table 2. The chopper and winder operators are exposed to much higher dust concentrations than the line operators, 0.54-0.8 mg/m^3 compared to 0.1-0.12 mg/m^3. Sampling conducted by Union Carbide/Amoco from 1985 through May 1986, shows overall carbon fiber levels ranging from 0.011 to less than 0.27 fibers/cc. This range is based on monitoring from all areas of the facility where worker exposure was deemed likely. Samples were analyzed using NIOSH P & CAM Method 239 (phase contrast optical microscopy) (Familia 1986).

Table 3 presents total and respirable dust monitoring data for the laboratory, winding, and production areas of a PAN-based carbon fiber production facility. Mean dust levels, analyzed gravimetrically, range from 0.08 mg/m^3-0.39 mg/m^3; approximately 40 percent of the airborne dust is respirable. Airborne dust concentrations are twice as high during winding than during production, but laboratory dust levels are the highest. The

Table 2. Worker Exposures at the Great Lakes Carbon Corporation Facility in Rockwood, TN

Sample Location	Nuisance Particulate Exposure[a] (mg/m^3)
Line Operator	0.12
Line Operator	0.10
Chopper Operator	0.80
4 to 1 Winder Operator	0.57
12 to 1 Winder Operator	0.54
12 to 1 Winder Operator	0.74

[a] Samples were analyzed gravimetrically.

Source: Gilliam 1986.

Table 3. Results of Samples Collected in Various Work Areas of a Carbon Fiber Production Facility

Sample Location	Number of Samples	Total Dust[a] (mg/m^3) Mean[b]	Total Dust[a] (mg/m^3) Standard Deviation	Respirable Dust[a] (mg/m^3) Mean[b]	Respirable Dust[a] (mg/m^3) Standard Deviation
Laboratory	7	0.39	0.31	0.16	0.09
Winding	5	0.19	0.17	0.07	0.05
Production	26	0.08	0.03	0.03	0.01

[a] Samples were analyzed gravimetrically.
[b] Arithmetic mean.

Source: Dahlquist 1984.

higher levels of dust collected in the laboratory are the result of cutting, grinding, and milling of carbon fiber-reinforced plastics for material's testing purposes. This dust contained a larger number of small mostly non-carbon, non-fibrous particles ranging from 0.5 to 7 μm in diameter. Those particles above 7 μm in diameter consisted of varying lengths of carbon fiber, still with no evidence of fibrillation (i.e., longitudinal fracture). The samples were analyzed for carbon fiber content by light microscopy; sample times ranged from 20 minutes to 8 hours (Dahlquist 1984).

Tables 4 and 5 illustrate sampling results for winding and several other operations in a PAN-based carbon fiber production facility. Airborne fiber concentrations during winding, prepregging, and weaving operations are extremely low (2.4×10^{-5} to 3.4×10^{-4} fibers/cc). The highest concentrations are experienced during weaving operations, particularly rapier weaving. In general, fiber diameters were reported to be relatively constant while lengths were widely distributed in a given sample. Airborne fibers are largely of nonrespirable size having average diameters ranging from 6.1 to 6.7 μm. However, airborne fibers from rapier weaving have an average diameter of 3.9 μm, and fiber widths were not as constant as they were for other operations; some fibers appeared damaged. Therefore, rapier weaving operations appear to have the highest potential for airborne respirable carbon fiber exposure although the observed exposure levels are quite low (Dahlquist 1984).

Currently little data exists on fiber size distributions for airborne carbon/graphite fiber or fly. One manufacturer, Union Carbide, indicated the intent to initiate a study in this area (Union Carbide 1986d). It is likely that due to the nominal fiber diameters (from 5.3 to greater than 8 micrometers) involved, very little of the actual fiber would penetrate into the

Table 4. Results of Samples of Emissions Collected During Winding Operations at a Carbon Fiber Production Plant[a]

Sample Number	Fibers/m^3	Average Length, μm	Average Width, μm	Mass ng/m^3
I	28	48	6.5	211
II	60	60	6.5	511
III	32	60	6.5	296
IV	64	50	6.5	908

[a] Analytical method used was phase contrast light microscopy.

Source: Dahlquist 1984.

Table 5. Results of Samples Collected Outside During Various Carbon Fiber Processing Operations[a]

Operation	Number Concentration, Fibers/m3	Average Length, µm	Average Width, µm	Mass Concentration, ng/m^3
Prepregging	24	213.1	6.1	356
Shuttle Loom Weaving	88	749.4	6.7	5,497
Rapier Weaving[b]	340	706.0	3.9	6,831

[a] Analytical method was not specified.

[b] Outside ambient, downstream of baghouse. Some fibers appeared damaged.

Source: Dahlquist 1984.

deep lung spaces (i.e., the alveoli). A study of a PAN-based carbon/graphite fiber production facility supports this theory in finding evidence of virtually constant diameters (8-10 µm) in airborne fiber samples (Jones 1982). Carbon/graphite fiber fly, a lint-like material formed from longitudinal fracturing of carbon/graphite fibers, may be significantly smaller in diameter than the actual fiber and thus pose an inhalation problem (Union Carbide 1986d).

B. Fiber Use

Carbon/graphite fibers are selected for use in many areas because of their unique set of properties. They possess high mechanical strength, high moduli of elasticity, and low density, in addition to being heat and chemical resistant. Two uses will be addressed in this section, carbon/graphite fibers in composite structures and carbon/graphite fibers in high temperature insulation applications. These two applications appear to have the highest potential for airborne respirable fiber exposure. Carbon/graphite fibers are also used in fabric form to reinforce ablative laminates for the aerospace industry and in high performance packing.

1. Composite Structures

Carbon/graphite fibers are placed in matrices, distributing loads uniformly over a wide area, to fully realize many of their advantages such as high physical strength and stiffness. The resultant product is known as a composite structure (Lubin 1982). Choice of matrix and carbon/graphite fiber components is done to achieve a product with specific characteristics and properties (Lubin 1982). Composite structures are attractive alternatives to conventional structural materials for several reasons: significant weight reduction; additional freedom in product design; greater product performance due to higher physical strength and lower weights; and special characteristics such as corrosion resistance, thermal stability, abrasiveness, and electrical properties (US DOC/ITA 1985).

Composite materials are available in many different forms. Typically, they are sold by manufacturers as "pre-pregs" (i.e., carbon/graphite fibers pre-impregnated with a matrix or blending compound). In this form, they are shipped partially cured, and they are usually refrigerated until use. In order to use them, they are first shaped using a variety of means (e.g., wrapping around a mandrel or pressure molding into a die) and then subject to heat to complete the curing process (Lubin 1982, MIT 1986).

Composites may also consist of engineering plastics reinforced with short lengths of carbon/graphite fiber (i.e., chopped fiber) imbedded in the matrix. These may be sold in pelletized (pre-mixed) form or be manufactured prior to use from dry fiber and matrix components.

a. Manufacturers

Carbon/graphite fiber composites are manufactured for a variety of applications by many different firms. There are approximately 10 manufacturers of pre-pregs and on the order of 100 manufacturers of carbon/graphite fiber composites in the United States. Companies surveyed for uses and production methodology information included: Advanced Composite Products Inc., Amalga Corporation, Boeing Aerospace Co., Hercules Aerospace, Kemlon Products/Keystone Engineering, and Sikorsky Aircraft. Uses encountered included cylinder/tube construction, rocket motor casings, body panels (end-user not specified), aircraft body panels, missile fins and nose cones, aircraft spoilers and ailerons. Advanced Composite Products Inc., Amalga Corp., and Kemlon Products/Keystone Engineering indicated that they were specialty manufacturers and would fabricate virtually any customer specified part (Advanced Composite Products Inc. 1986, Amalga Corp. 1986, Kemlon Products/Keystone Engineering 1986).

All manufacturers contacted used carbon/graphite fiber composites in the form of pre-pregs. Only one, Boeing Aerospace Co., indicated that they had ever used dry fiber; dry fiber use was discontinued several years ago due to handling and product consistency difficulties (Boeing Aerospace Co. 1986). Advanced Composite Products Inc., the only producer of reinforced plastics surveyed, indicated that they purchased the matrix/chopped carbon/graphite fiber as a manufactured blended compound and thus, handled no dry fiber (Advanced Composite Products Inc. 1986).

b. Manufacturing Processes/Potential Exposure Points

All producers of carbon/graphite fiber composite structures indicated that there was no fiber exposure in the creation of the basic structure product because of the use of prepregs. Once the fibers are bound in a matrix, most manufacturers and users agree that there is no carbon/graphite fiber exposure problem (Hercules Aerospace 1986, Union Carbide 1986e, Advanced Composite Products Inc. 1986) Similarly, in reinforced plastics production, once the chopped carbon/graphite fibers were bound in the extruded pellets, there is no carbon/graphite fiber exposure problem (Advanced Composite Products Inc. 1986, Hercules Aerospace 1986). Most users believe that the only likely fiber exposure would be in finishing operations such as sanding, drilling, or grinding (Sikorsky Aircraft 1986, Boeing Aerospace Co. 1986, Advanced Composite Products Inc. 1986, Hercules Aerospace 1986, Union Carbide 1986e).

(1) Process Description and Automation

Figure 2 shows the process flow for manufacturing carbon/graphite fiber composites. Several different production methods are discussed below.

Pre-Preg Manufacture. Pre-pregs are manufactured by impregnating continuous carbon/graphite fibers or fabric with a matrix, typically an epoxy resin compound. Initially, the fibers are arranged in the desired configuration (e.g., tape, filament, fabric) called a tow. After being slightly flattened, the tow may be passed through a bath containing the matrix. The tow is then dried, allowed to preharden, refrigerated, and wound into a storage configuration. The pre-preg may be further processed or shipped as is to the final user (MIT 1986). Alternately, one manufacturer, Union Carbide/Amoco, indicated that they impregnate fibers by spreading a layer of resin on a release paper, laying the fibers down parallel to one another into the substrate, and compressing the two together. A second layer of resin is then applied, effectively creating a sandwich (Union Carbide 1986e). To assure product uniformity, pre-pregging operations are typically highly automated with little manual intervention necessary (Union Carbide 1986e).

One manufacturer indicated worker exposure to carbon/graphite fibers is limited to workers involved in the stringing up (loading) of the machine with dry fiber on creels (Union Carbide 1986e). The rest of the process is automated. Another manufacturer cited little to no concern about fiber exposure in pre-preg operations as a whole because liberal application of sizing materials minimize or eliminate any carbon fiber fly formation (Hercules Aerospace 1986).

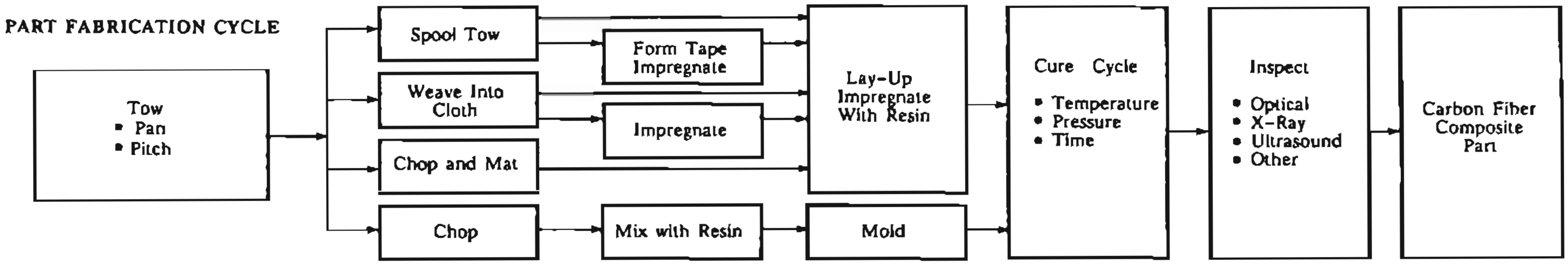

Figure 2. Carbon fiber composite material production process. (Source: Zumwalde 1980.)

Reinforced Plastic Manufacture. Reinforced plastics are manufactured by imbedding short lengths of carbon/graphite fiber within a matrix. The raw materials, chopped fiber and resin pellets, are blended together in a Banbury or paddle-type mixer to create a dry mix. One manufacturer, LNP Corporation, indicated that carbon fibers are transferred manually from their original shipping containers (fiberboard boxes) to weighing scales and then to the mixer. Fibers are highly sized and display cohesive rather than dispersive properties. Once the raw materials are loaded into the mixer, the mixer is sealed and operated for a typical cycle time of 25-30 seconds. A hopper-feed system and auger are used to transfer the dry mix to an extruder where it is heated to melting (resin melting point), extruded into lines, and chopped to form pellets. LNP Corporation cited low to non-detectable fiber concentrations during routine operations, even during initial materials handling (i.e., transferring fiber from containers to weighing scales or the mixer) (LNP 1986). It is likely that the only exposure to dry fibers will be in the materials handling stage (i.e., addition of fiber to the mixer) (ICF Inc. 1985).

Wet Winding Operations. Fibers may also be used directly (i.e., without an intermediate pre-preg step) to create composite structures. A tow is run through a bath containing the matrix resin and wound directly on a mandrel (mold). The wound fiber/resin combination is subject to heat and humidity causing it to cure into the desired configuration (Hercules Aerospace 1986).

Worker exposure to airborne fibers is believed to be minimal because of the liberal applications of sizing materials to the carbon filament. This should serve to minimize or eliminate any fly formation.

Composite Structure Finishing. After creating the basic composite structure, it may be necessary to alter its final form to meet design criteria. For example, drilling, cutting, sanding, or grinding may be necessary before a product is ready for use or shipment; hand held tool edging and trimming is common practice (NIOSH 1983). Most manufacturers believe that these operations may pose the greatest potential for fiber and other exposures; therefore, engineering controls are usually used in these operations.

(2) Engineering Controls and Protective Equipment

Exposure to carbon/graphite fibers in pre-preg production is controlled through the use of engineering controls. Local exhaust ventilation and process automation are typically used (Union Carbide 1986e, Hercules Aerospace 1986). Dust masks are provided in pre-preg and composite manufacturing operations, but their use is optional. Workers do not use any additional protective equipment. Most workers wear street clothes, although some may wear a shop coat (Boeing Aerospace Co. 1986). A combination of ventilation, automation, and product design (i.e., liberal application of sizing) are used to control fiber emissions from wet-winding operations (Hercules Aerospace 1986). Little user data were available regarding engineering controls or protective equipment in the production of reinforced plastics. LNP Corporation indicated the use of "elephant trunks" (i.e., portable exhaust ducts) to control fiber and dust emissions. Personal protective equipment in the form of dust masks and "paper" suits are mandatory. Once the fiber is imbedded in the matrix blend, fiber exposure is unlikely.

Engineering controls for finishing operations may take several forms. A common control method is use of water sprays to minimize dust emissions from finishing operations (Hercules Aerospace 1986, Sikorsky Aircraft 1986). For products that will not tolerate water, use of vacuum sources in equipment, local exhaust ventilation, and general dilution ventilation are the preferred control methods (Hercules Aerospace 1986, Sikorsky Aircraft 1986, Amalga Corp. 1986, NIOSH 1983). In addition, use of separate rooms for finishing steps was cited by one user (Advanced Composite Products Inc. 1986).

c. Extent of Potential Exposure

Hercules employs approximately 250 people in both the production of carbon/graphic fibers and in the manufacture of pre-pegs. Information on how many of these employees work only on the pre-preg lines has not been made available. In addition, Hercules employs between 400 and 500 workers in the manufacture of composite structures. Manufacturing operations run 365 days/year and 24 hours/day (Hercules Aerospace 1986). Boeing Aerospace Co. employs the same number of employees as Hercules in each manufacturing operation. They also operate 365 days/year and 24 hours/day (Boeing Aerospace Co. 1986).

LNP Corporation, a manufacturer of dry mixes for carbon fiber reinforced plastics, cited only two workers potentially exposed to carbon fibers: a mixer and a machine operator. The production line operates 5 days/week and 3 shifts (24 hours)/day. Total operating time for carbon fiber dry mix production is 50-60 days/year.

Exposure data could not be obtained for the composite manufacturing processes; however, some insight into the potential airborne fiber size can be obtained through data on exposure during machining and during airplane crashes/fires.

Studies of the dust produced during drilling, cutting, sanding, and grinding concluded that the majority of the respirable fraction consisted of non-carbon, non-fibrous particles ranging from 0.5 to 7 μm in diameter (Dahlquist 1984). A study conducted by the U.S. Environmental Protection Agency's Environmental Sciences Research Laboratory concluded that fibers were released in sawing and drilling operations. These fibers typically ranged from 50 to 100 μm in length; some evidence of longitudinal cleaving was present giving potential for smaller, respirable size fiber formation (Wagman et al. 1979).

Accidents involving aircraft constructed with carbon fiber reinforced components may involve the release of carbon fibers (USAF 1982). In an attempt to estimate the risks associated with carbon fiber release from composites during aircraft accidents, the National Aeronautics and Space Administration (NASA) conducted a series of tests on potential airborne exposure to carbon/graphite fibers in aircraft crash/fire situations. The tests conducted by NASA involved the burning of carbon/graphite composites to determine the number and sizes of released carbon fibers. Fiber lengths measured averaged between 2-3 mm. Fibers smaller than 1 mm in length account for 67-74 mass percent of the total fibers released in undisturbed fires; in fires with accompanying explosions, this percentage increases to 98 mass percent. When fiber diameters were evaluated for fibers longer than 1 mm the average fiber diameter was found to be 4.0-4.7 μm, reduced from initial diameters of 7-8 μm for the product material (Zumwalde 1980).

It was estimated that fewer than 24 percent of the fibers released fell into the respirable size range (i.e., lengths less than 80 μm and diameters less than 3 μm). The average fiber diameter of the respirable fibers was found to be 1.5 μm, and the average length was 30 μm. The reduction in diameter appears to be the result of fibrillation (longitudinal splitting) and oxidation effects (Zumwalde 1980). It was estimated that the number of respirable fibers generated per kilogram of carbon fiber released during an aircraft accident and fire was 5 x 10^5 fibers/cc. This mass fraction is 5 percent of the total fiber released. Total peak exposure was determined to be approximately 5 fibers/cc (Zumwalde 1980).

It must be emphasized that these aircraft crash/fire tests represent abnormally severe conditions for the majority of carbon fiber applications and, therefore, any exposure data derived from these studies may not be directly applicable to normal day-to-day carbon fiber composite use.

2. High Temperature Insulation

Another application for carbon fiber products is in high temperature insulation. Processed into felt form, carbon fiber possess several advantages in this application: increased temperature uniformity, low mass insulation for reduced cooling time, minimal adsorption, resistance to high temperature, and shape retention. In addition, excellent pumpdown capability, easy installation and attachment, and fiber construction along with paper and foil facing and coating (Rigidseal™) prevent dusting and erosion due to high velocity cooling cycle gas flows (Ferrito 1986). Carbon felts are used in non-oxidizing, inert atmosphere applications since the felt has a tendency to oxidize easily.

a. Manufacturers

Polycarbon Inc. is the only manufacturer of carbon felt products for insulation identified by ICF (Polycarbon Inc. 1986).

b. Manufacturing Processes/Potential Exposure Points

Carbon fiber felts are manufactured in a similiar fashion to carbon fibers. Typically the precursor, rayon, is needlepunched prior to oxidation or carbonization. The felt material is then oxidized for a period of approximately two weeks, after which it is carbonized. The intent of the carbonization process is not to develop high stiffness (modulus) or strength properties but rather to develop a pure, inert material. High stiffness is in fact undesirable, so the felt is not graphitized. Processing is done in a batch manner rather than in a continuous fashion as in fiber production (Polycarbon 1986).

Installation of the felt product may be done with scissors and graphite thread. The felt is cut to fit and is then sewn together in a desired configuration. Rigid felt is installed in a similar fashion; the felt is cut to fit and may be bolted into the furnace walls, taking care to avoid heat loss through fastener materials. Information on installation procedures for insulation materials and number of workers is being collected. No data is available on exposure to carbon fibers during insulation installation operations.

c. Engineering Controls and Personal Protective Equipment

Engineering controls for felt production are described in the carbon fiber manufacturing section of this document. Workers in the production area wear coveralls and dust masks (Polycarbon Inc. 1986). Data on engineering controls and personal protective equipment for insulation installation operations is being researched.

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V. CERAMIC FIBER

Ceramic fibers are produced from molten glass or by thermal chemical processing using either kaolin clay or a combination of alumina (Al_2O_3) and silica (SiO_2) as the base raw materials. Zirconia, boria, and other metallic oxides may be added in the process to produce specialty ceramic fibers. Ceramic fibers have high termperature resistance and are often referred to as Refractory Ceramic Fibers (RCF) or simply refractory fibers. ASTM defines refractory fiber as "nonmetallic, inorganic, continuous or non-continuous filaments having those chemical and physical properties that make them applicable for structures or as components of systems that are exposed to environments above 1000°F (583°C)" (Babcock and Wilcox 1986b). Refractory fibers are primarily used for high temperature insulation applications, including thermal blankets for industrial furnaces and vacuum formed parts for specialty products with high temperature tolerances. Most products manufactured from non-continuous refractory fibers contain fibers that range in nominal diameter from 2 to 4 µm and that range in actual diameter from 0.1 to 10 µm (Babcock & Wilcox 1986b). The average diameter of refractory fibers is 1 to 4 microns. The length of the non-continuous fibers varies from 0.03 to 12 inches. Continuous ceramic fibers have nominal diameters ranging from 11 to 20 microns. Products made from continuous fibers include fabrics, tapes, sleeving, and cordage. Both non-continuous and continuous fibers exhibit low thermal conductivity, high temperature resistance, and electrical non-conductivity.

A. Non-Continuous Fibers

1. Fiber Production

a. Fiber Producers

The production of ceramic fibers began in the 1940s on an experimental basis; however, production of these fibers did not reach a significant level until the early 1970s. This was primarily due to the oil shortage which created a need for improved high temperature fiber forms (ICF 1986b). Currently, the five major U.S. producers of non-continuous ceramic fibers are the Manville Corporation, C-E Refractories, Standard Oil-Carborundum (hereafter referred to as Carborundum), Babcock & Wilcox, and A.P. Green Refractories. Each has one plant in the U.S. with the exception of Carborundum which has four and Babcock & Wilcox which has three. Table 1 lists each of the major fiber producers, their plant locations, and general information on the fiber being produced. The facilities each operate 24 hours/day and between 300 and 365 days/year (C-E Refractories 1986b).

b. Fiber Production Process/Potential Exposure Points

(1) Process Description and Automation

A general process flow diagram illustrating how non-continuous refractory ceramic fibers are produced in the U.S. is shown in Figure 1. The producers of non-continuous refractory ceramic fibers use two different production processes: the 'spun' process and the 'blown' process. These two processes differ only in the third step of the production process, attenuation of the molten glass into a fiber; and the fibers produced are interchangeable in their applications. In the spun process, a spinning wheel is used to attenuate the glass into filaments averaging 8 to 12 inches long. The blown process uses a stream of blown air producing fibers averaging 1 to 2 inches long. The spun process is newer than the blown process and offers the

Table 1. Major U.S. Producers of Non-Continuous Refractory Ceramic Fibers

Company	Fiber Name	Plant Location(s)	Annual Capacity[a] (millions of pounds)	Process
A.P. Green Refractories	Inswool®	Pyor, OK	3	Spun
Babcock & Wilcox	Kaowool®	Augusta, GA Emporia, KS Ponce, PR	40	Blown
C-E Refractories	CER-Wool®	Erwin, TN	10	Spun
Carborundum	Fiberfrax®	Niagara Falls, NY (3) New Carlisle, IN	55	Spun and Blown
Manville	Cerawool™ Cera Fiber® Cerachrome™ Cerachem®	Waukegan, IL	20	Spun

[a] Annual capacity as of January 1, 1984 (SRI 1985).

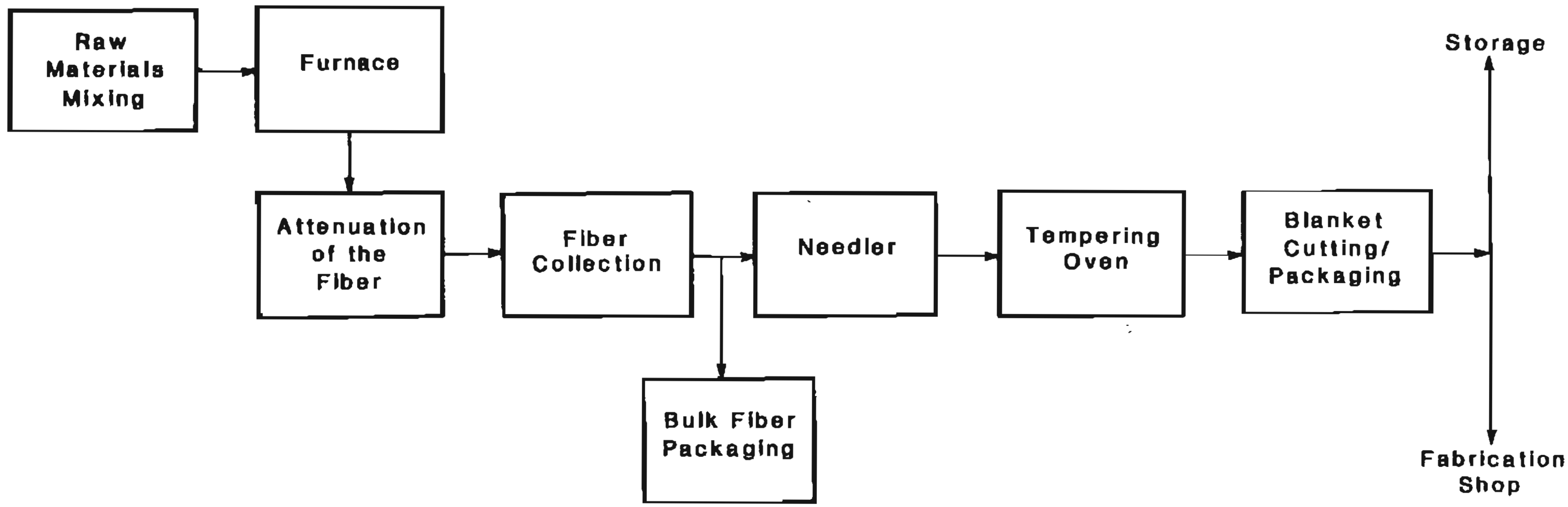

Figure 1. Non-continuous refractory ceramic fibers -- primary processes.

advantage of producing longer fibers with a narrower range of fiber diameters. Both processes are continuous, beginning at the mixing of the raw materials and ending with the fiber in a blanket form.

Some companies also produce 'bulk' fiber which is simply ceramic fiber in its most basic form. Bulk fiber is taken off the production line halfway through the process. In its unprocessed state, bulk fiber is used as packing or loose fill in expansion joints, furnace-crown cavities, and wall cavities. Bulk fiber may also be further processed into paper and board (see Section 2, Fiber Use).

Descriptions of blanket manufacture and bulk fiber packaging are presented below.

<u>Raw Materials Mixing</u>. The batching process may be automated (A.P. Green Refractories 1986). All weighing, mixing, etc. is done under the control of an automatic system. After weighing, the materials are automatically transferred to a tumbler where they are thoroughly mixed; the mixed raw materials are then transferred to the furnace (Endicott 1981). The number of employees involved in the mixing process may range from zero to two. (Some manufacturers do not include a mixing step in their process (Babcock & Wilcox 1986b).)

<u>Furnace</u>. The alumina/silica mixture is subjected to temperatures between 2800°F and 3800°F in the furnace. When the molten glass reaches the proper temperature and viscosity, it drops through an orifice in the furnace onto a set of spinning wheels (if the spun process is used) or into a stream of air (if the blown process is used). Usually there is one operator in the furnace area. The furnace operator generally remains in a separate control area except when sampling or troubleshooting is required.

Attenuation of the Fiber. Fiberization begins once the molten stream leaves the furnace. The molten glass is either blown with an air stream or fiberized with spinning wheels to produce fibers which flow into a collection chamber. Fans are sometimes used to blow the fibers into the collection chamber. The furnace operator usually oversees this area of the process also. Again, the process is automated, and the operator generally remains in an isolated control area. The process is open at this point, but due to the vacuum in the collection chamber, the fibers are not likely to be emitted into the work area.

Fiber Collection. A partial vacuum pulls the fibers into the collection chamber, where they settle onto a belt in the form of a mat. There are no employees in this area. The fiber mats are sent automatically to the needler. If the company is also selling the fiber in its bulk form, the bulk fiber is pulled off the line at this point to be packaged.

Bulk Fiber Packaging. If the bulk fiber is being sold in addition to the blanket form, the fiber is automatically diverted to a bulk fiber bagging station. In some plants the bulk fiber is taken off-line manually and placed in boxes for later shipment. Other plants have an automated system. The employee places a paper bag or box on an automated baler, boxer, bagger machine, and it is filled with the fiber (Manville 1986c). Usually one or two employees are needed; these are sometimes the same employees who work at the end of the line boxing the blanket.

Needler. In order to increase its strength, the mat passes through a needle felting machine where the fibers are interlocked by steel needles, and the newly formed "blanket" is compressed to its final thickness. One operator may oversee numerous needle machines.

Tempering Oven. The fibers receive a coat of lubricant to allow needle felting. The lubricant residue left on the blanket is removed by drying in a tempering oven. There are no employees at this point.

Blanket Cutting/Packaging. The blanket is cut to its desired size and packaged. Most companies use automated cutting machines to trim the blanket to its final size, and windup machines to roll the blanket for packaging. Usually one to two employees are needed to actually box the product. The boxes are either placed in storage for later shipment to the customer or sent to a fabricating shop for further processing.

(2) Engineering Controls and Protective Equipment

All the ceramic fiber producers use a dust collection system in their plants (A.P. Green Refractories 1986, Babcock & Wilcox 1986a, C-E Refractories 1986b, Carborundum 1986a, Manville 1986a). Localized exhaust systems (baghouse type) are used to the extent the individual producers feel necessary; however, they all use general ventilation wherever local is not used. Since the process is almost fully automated as well as enclosed, producers generally do not see a need for localized ventilation throughout the plant.

All the producers provide gloves and coveralls to their employees; however, their use is optional. The employees are required to wear eye protection. The ceramic fiber producers use the following guidelines in recommending the use of respirators to their employees (Carborundum 1986b):

- ≤2 fibers/cc airborne: no additional protective equipment needed
- 2-5 fibers/cc airborne: respiratory mask
- 5-50 fibers/cc airborne: full face mask with filter
- ≥50 fibers/cc airborne: full face mask with supplied air

Employees are also strongly encouraged to submit to periodic medical examinations.

c. Extent of Potential Exposure

(1) Number of Persons Exposed/Duration of Exposure

A list of the employee job functions found at a non-continuous refractory ceramic fiber production plant is presented in Table 2; a total of between 4 and 10 people work in these positions at each plant. A total of 600 employees have worked in the manufacturing of non-continuous refractory ceramic fibers up through this year. This figure includes all employees, past and present, potentially exposed (Manville 1986a). These production facilities each operate 24 hours/day and between 300 and 365 days/year (C-E Refractories 1986b).

(2) Respirability of Airborne Fibers

Monitoring data for C-E Refractories are presented in Table 3 (C-E Refractories 1986a). Personal samples were taken, using an air intake of 2 liters/minute, to characterize breathing zone exposure levels. Phase contrast optical microscopy was used to determine the fiber concentrations. The monitoring data is for two of the employees on the production line, the furnace operator and the employee who takes the blanket off the end of the line to be packaged (the slitter/cutter/packer). The fiber concentrations were found to be 0.008 and 0.009 fibers/cc for the furnace operator and the slitter/cutter/packager, respectively. Both employees work a full 8-hour shift at their stations (C-E Refractories 1986b).

Monitoring data for Carborundum's five facilities are presented in Table 4 (SOHIO/Carborundum 1985). Fiber concentrations were determined using phase contrast optical microscopy. Fiber concentrations vary between 0.01 and 2.50 fibers/cc. Mean fiber concentrations range from 0.14 to 0.66 fibers/cc.

Table 2. Potential Employee Exposure -- Non-Continuous Refractory Fiber Production

Number of Employees	Position	Extent of Exposure	Personal Protective Clothing
0-2	Raw Materials Handler(s)	No exposure to fibers, only dust from raw materials (silica...).	
1	Furnace Operator	Generally in control room; therefore, minimum risk of exposure; also supervises spinning operations.	
1	Needler Operator	May oversee several lines; slightly higher potential for exposure. May also oversee the tempering oven.	
1-2	Slit/Cut/Pack Employee(s)	Boxes the product at the end of the line; exposures may be slightly higher since employees are working directly with the fibers.	Gloves and coveralls.
0-2	Utility Workers	Work throughout the process; exposures vary.	
1-2	Maintenance	Exposures vary.	

Sources: A.P. Green Refractories 1986, Babcock & Wilcox 1986a, C-E Refractories 1986b, Carborundum 1986a, Manville 1986a.

Table 3. Monitoring Results for C-E Refractories Production Facility

Sample Location	Total Sample Time (hr)	Fiber Concentration[a] (fibers/cc)
Furnace Operator	6.50	0.008
Slitter, Cutter, Packer	6.75	0.009

[a] Fiber concentrations were determined using phase contrast optical microscopy.

Source: C-E Refractories 1986a.

Table 4. Monitoring Results for Carborundum Production Facilities

Facility	Concentration Range[a] (fibers/cc)	Arithmetic Mean (fibers/cc)	Number of Samples	Deviation (fibers/cc)
New Carlisle, IN	0.01-2.50	0.45	116	0.47
Niagara Falls, NY	0.11-2.31	0.66	10	0.68
Amherst, NY	0.01-0.26	0.14	8	0.08
Sanborn, NY	0.04-1.01	0.44	4	0.42
Whirlpool Technical Center Niagara Falls, NY	0.10-0.68	0.29	4	0.27

[a] Fiber concentrations determined using phase contrast optical microscopy.

Source: SOHIO/Carborundum 1985.

Additional information on individual employee exposure potentials at Carborundum facilities has been conducted and will be incorporated upon receipt.

Monitoring data for the Manville Corporation facility are presented in Table 5. Monitoring data were taken for the furnace operator, the needler operator, the slitter/cutter/packer, the employees at the job center, and the machine tender. The job center is a labor pool; these employees are used to salvage the product, process special orders, and perform general clean-up operations. The machine tender watches over the entire operation (Manville 1986c). Fiber concentrations were determined using phase contrast optical microscopy (Manville 1986a). The airborne fiber concentrations vary from 0.1 to 0.9 fibers/cc; the slitter/cutter/packer and the job center employees are exposed to the highest fiber concentrations.

A study on occupational exposure to ceramic fibers in the workplace was performed by Nurtan Esmen of the University of Pittsburgh in 1976 (Esmen et al. 1979, Esmen and Hammond 1982); the results of this study are shown in Tables 6 and 7. Three U.S. production facilities each producing ceramic fibers with nominal diameters between 2 and 4 µm were included in this study. Personal samples were collected from within the breathing zones of the employees, and counting and sizing of fibers were performed by combined optical and electron microscopy for each sample. The sensitivity of the optical microscopy counting procedure was 0.0012 fibers/cc; the sensitivity of the electron microscopy counting procedure was 0.0023 fibers/cc. Data in Table 6 indicate that the average exposure of employees varied from 0.04 to 0.73 fibers/cc for plant A, 0.27 to 0.60 for plant B, and 0.01 to 0.04 for plant C (Esmen et al. 1979). Exposures ranged from 0.02-1.5 fibers/cc for plant A, 0.08-0.88 fibers/cc for plant B, and 0.001-0.21 fibers/cc for plant C.

Table 5. Monitoring Results for Manville Production Facility

Sample Location	Number of Samples	Fiber Concentrations (fiber/cc)
Furnace Operator	2	≤0.1 ≤0.1
Needler Operator	3	≤0.1 0.1 0.2
Slitter/Cutter/Packer	4	0.2 0.2 0.9 0.1
Job Center	2	0.4 0.3
Machine Tender	2	0.2 ≤0.2

Note: All data is from 1985, except for the machine tender which is from 1984. Fiber concentrations determined using phase contrast optical microscopy.

Source: Manville Corporation 1986c.

Table 6. Results (Airborne Fiber Concentrations) of Esmen Study on Worker Exposure Levels in Three Refractory Ceramic Fiber Production Facilities

Plant/Sample Location	Number of Samples	Average Fiber Concentration (fibers/cc)	Range of Concentrations (fibers/cc)
Plant A			
Furnace Operator -- Lines 1 and 2	6	0.73	0.26-1.40
Furnace Operator -- Lines 3 and 4	3	0.041	0.02-0.066
Shipping (Forklift Operator)	4	0.22	0.12-0.34
Quality Control	4	0.11	0.023-0.16
Maintenance	6	0.52	0.20-1.5
Plant B			
Furnace Operator	4	0.60	0.40-0.88
Maintenance	19	0.27	0.079-0.84
Quality Control	5	0.33	0.13-0.74
Plant C			
Furnace Operator	9	0.037	0.0023-0.210
Maintenance	14	0.013	0.0012-0.032
Job Center	7	0.027	0.005-0.069

Note: Total fiber concentration determined by phase contrast optical microscopy.

Source: Esmen et al. 1979.

Table 7. Composite Size Distribution Expressed as a Percentage of Total Fiber Associated with the Size/Length Class

Fiber Length (μm)	Fiber Diameter (μm) ≤0.2	0.2-0.6	0.6-1	1-3	3-5	≥5	Σ% Length	Σ Diameter (Σ% Length)
Plant A								
≤1	0.5	0.4	x	x	x	x	0.9	0.9
1- 5	2.2	4.6	1.9	0.4	x	x	9.1	10.0
5-20	4.1	6.0	4.4	18.2	5.6	0.8	39.1	49.1
≥20	0.8	4.8	2.3	22.6	12.4	7.9	50.8	99.9
Σ% Diameter	7.6	15.8	8.6	41.2	18.0	8.7		
Σ Length (Σ% Diameter)	7.6	23.4	32.0	73.2	91.2			
Plant B								
≤1	0.3	0.5	x	x	x	x	0.8	0.8
1- 5	2.7	3.1	0.5	0.2	x	x	6.5	7.3
5-20	5.6	7.6	5.3	15.7	2.3	0.2	36.7	44.0
≥20	2.9	8.4	4.3	29.6	4.8	6.0	56.0	100.0
Σ% Diameter	11.5	19.6	10.1	45.5	7.1	6.2		
Σ Length (Σ% Diameter)	11.5	31.1	41.2	86.7	93.8	100.0		
Plant C								
≤1	0.5	0.3	x	x	x	x	0.8	0.8
1- 5	4.7	10.6	1.7	3.0	x	x	20.0	20.8
5-20	5.9	18.1	4.9	13.6	0.5	0.02	43.0	63.8
≥20	1.5	6.4	4.7	17.9	4.5	1.2	36.2	100.0
Σ% Diameter	12.6	35.4	11.3	34.5	5.0	1.2		
Σ Length (Σ% Diameter)	12.6	48.0	59.3	93.8	98.8	100.0		

X = zero.

Note: Size distribution determined using optical microscopy.

Source: Esmen and Hammand 1982.

The furnace operators are exposed to the highest airborne fiber concentrations in all three facilities (average concentrations range from 0.037-0.73 fibers/cc). Significant measures have been taken by manufacturers in the last few years to reduce airborne exposure levels; ventilation systems have been expanded and more protective measures have been taken (A.P. Green Refractories 1986).

Fiber size distributions from the Esmen study are presented in Table 7. Although there were some operational diversities among the plants investigated, the size and length distributions of airborne fibers in the facilities were consistent (see Figure 2). Approximately 90 percent of airborne fibers were less than 3.5 μm in diameter (i.e., of respirable size), with a geometric mean diameter of ~0.7 μm and a geometric mean length of 13 μm (Esmen et al. 1979).

2. Fiber Use

The range of uses of non-continuous refractory ceramic fibers has changed significantly over the last 15 to 20 years. The fibers were first developed in the 1940's. Initially, high production costs limited their uses to special high technology applications and the aerospace industry. During the late 1960's, the increasing costs of other insulating refractories and of energy, made the use of ceramic fibers for furnace and kiln linings more economical. At the same time, a gradual increase in process operating temperatures was being seen in the Chemical Processing Industry, necessitating the development of improved high temperature refractories. Ceramic fiber blanket linings have since been successfully utilized at temperatures up to 3000°F (Young 1981). Within the last few years, a substantial range of product forms have been introduced into the market -- including bulk, paper,

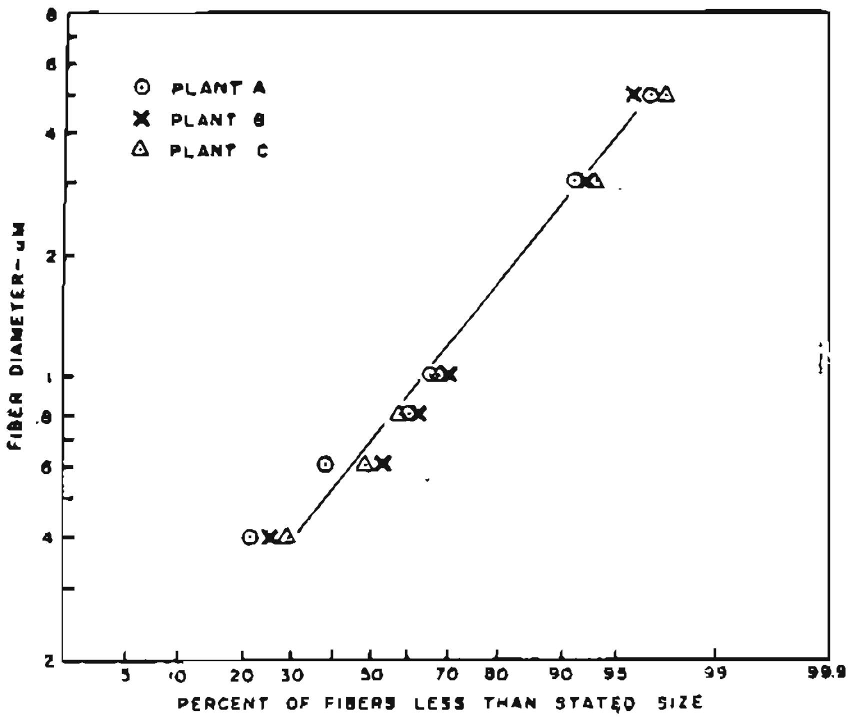

Figure 2. Fiber diameter distribution of airborne ceramic fibers. (Source: Esmen et al. 1979.)

felt, rigid and semi-rigid boards, and vacuum formed shapes. Table 8 shows the range of forms available and their applications.

Non-continuous ceramic fiber is produced in two forms, bulk fiber and blanket. Bulk fiber is used to manufacture ceramic felts, boards, papers, and vacuum formed shapes. Descriptions of the manufacturing processes for these products are provided below. Ceramic blanket need only be cut to its desired size in "fabrication shops" before use. Fabrication is considered part of the manufacturing process for all ceramic products and is also described in this section. Exposures during installation and removal of refractory ceramic fiber products are expected to be relatively high; these operations are discussed in Section d below.

a. Paper/Board/Felt Manufacture

(1) Manufacturers

The three manufacturers of ceramic paper and board in the U.S. are Lydall, James River, and Carborundum. Ceramic board is produced by other manufacturers as well, including Babcock & Wilcox and Manville. This list of board manufacturers is not all inclusive; the total number of manufacturers does not exceed ten (C-E Refractories 1986b). Paper applications include high-temperature gaskets, linings for combustion chambers, and thermal insulation for small clearances. Board is used for expansion joints in brick construction; other applications include backup insulation for furnaces and kilns. Felts are used instead of blankets when a semi-rigid insulating sheet is required.

(2) Manufacturing Process/Potential Exposure Points

Ceramic paper, board, and felt are all manufactured using the same basic process steps found in the fiberglass papermaking industry. A description of the fiberglass papermaking process and the associated

Table 8. Major Applications of Non-Continuous Refractory Ceramic Fiber Forms

Product Form	Major Applications	Properties Important for Use	Percentage of Fiber Consumed in Form
Blanket/Felt/ Modules	Furnace, kiln lining; firewall protection; high temperature gaskets and seals for expansion joints; turbines; insulation wraps	Low thermal conductivity; flexibility; strength	50%
Bulk	Fill in packing material for expansion joints; furnace base seals	Resiliency	10%
Board	Expansion joints; furnace, kiln back-up insulation; furnace lining; heat shields	Resiliency, rigidness	8%
Paper	Thermal, electrical insulators; combustion chamber linings; ingot mold linings	Low thermal, electrical conductivity	6%
Vacuum-Formed Shapes	Furnace linings (boards), insulation for special foundry components		12%
Mixes, Textiles (Cloth, Rope, sleeving) and Miscellaneous	Patching refractory cracks and fissures; composite insulations for space firings and launchings; cloth (furnace curtains, welding curtains and blankets); sleeving (tube protection, cable insulation)	Resiliency; good insulating properties	14%

Source: ICF 1986b.

engineering controls and protective equipment used is found in Section B.1 of Chapter VII, Fiberglass. In the case of ceramic fiber products, the process begins with the mixing of the bulk fiber with water to form a slurry. The bulk fiber may range in diameter from 0.1 to 10 microns and may vary in length from 0.3 to 12 inches. Retention agents are added in ceramic paper manufacture to prevent the formation of a foam. In the production of felt, phenolic resins may be added to strengthen the felt.

Boards and some felt products are not made in a continuous sheet like paper. Instead, sheets are wound continuously onto a cylindrical wire screen until the desired board thickness is obtained. The sheet is then removed from the cylinder and dried (ICF 1986a). After drying, the board is taken off line and packaged by hand.

Papermaking is a semi-automatic process, with raw materials being pulped in batches and fed to a continuous papermaking machine. Rolls of finished paper are cut from the machine and removed manually for packaging or further processing. The raw material handling operations in the beater area and the cutting and finishing operations have the potential to generate airborne fibers; local ventilation is used in these areas. Personal protective equipment is not used. Eight to 10 people work on a papermaking line; two of these workers are beater operators who add the bulk fiber to the pulper.

(3) Extent of Potential Exposure

The operation expected to generate the greatest exposure to airborne fibers is the fiber introduction operation. Stock preparation is commonly performed manually. Bags of bulk fiber are manually opened and dumped either onto a conveyor belt which discharges the fibers into the mixing tank, or poured directly into the tank for mixing (Carborundum 1986a, Lydall 1986b, James River 1986).

The Esmen study, which was discussed earlier, also included data on worker exposure levels during manufacturing operations for felts and vacuum formed shapes, and during fabrication. The results of the study are presented in Table 9. The data were not presented for specific areas within each manufacturing line. Exposure levels during felt manufacture varied between 0.027 and 0.29 fibers/cc in plant C (0.1 fibers/cc average), and 0.20 to 3.40 fibers/cc in plant B (1.1 fibers/cc average). During vacuum forming, levels ranged between 0.12 and 23 fibers/cc in plant A (4.3 fibers/cc average).

b. Manufacture of Vacuum Formed Shapes

(1) Manufacturers

Vacuum formed shapes are used in many areas including smelting, casting, and foundry operations as top-out or top hole plug cones, feeder tubes, ladle linings, and dip tubes. Additional applications include high temperature pipe insulation, thermal battery liners, heating-element support pads, and lining and insulation for automatic catalytic converters to reduce air pollution from car engine exhausts. All the major manufacturers of non-continuous refractory ceramic fibers (A.P. Green Refractories, Babcock & Wilcox, C-E Refractories, Carborundum, and Manville) manufacture vacuum formed shapes plus, there are many independent companies manufacturing them (C-E Refractories 1986b). The number of independent companies involved in the manufacture of vacuum formed shapes is not known; however, the number is larger than those involved in paper or board manufacture (C-E Refractories 1986b).

(2) Manufacturing Process/Potential Exposure Points

The vacuum forming process is very similar to papermaking in that bulk fibers and binders are dispersed in an aqueous slurry which is collected on a perforated mold. As in papermaking, the bags of bulk fiber are

Table 9. Results (Airborne Fiber Concentrations) of Esmen Study on Worker Exposure During Manufacturing

Plant/Operation	Number of Samples	Average Fiber Concentrations (fibers/cc)	Range of Concentrations (fibers/cc)
Plant A			
Vacuum Forming Equipment Operator	9	4.3	0.12-23
Vaccum Formed Shapes-Fabrication	13	7.6	0.7-56
Blanket Fabrication	5	0.74	0.29-1.7
Plant B			
Felt Manufacture	19	1.1	0.2-3.4
Plant C			
Felt Manufacture	13	0.1	0.027-0.29
Press Operator	4	0.076	0.035-0.10

Note: Total fiber concentration determined by phase contrast optical microscopy.

Source: Esmen et al. 1979.

opened by hand and dumped onto a conveyor belt leading to a mixing tank. The difference between vacuum forming and papermaking is in the paper formation step. In vacuum forming, the product is formed by drawing away the water by suction through the perforated mold instead of through a cylindrical screen. After forming, the bonded shape is stripped from the mold and dried to remove all excess water. Unlike the papermaking process, vacuum forming is normally carried out as a batch process (Harris et al. 1982).

(3) Extent of Potential Exposure

Refer to Section a on the Extent of Potential Exposure for Ceramic Paper/Board/Felt.

c. Fabrication (Paper/Board/Felt/Blanket)

(1) Fabricators

Most ceramic fiber products are custom made to the size and shape desired at the manufacturing facility. There are separate areas in the plant, known as fabrication shops, where this is done. Each of the five refractory ceramic fiber manufacturers have a fabrication shop on the premises. These shops operate 8 hours/day; the number of days/year they operate varies according to customer demand (Manville 1986a). In addition, many contractors have fabrication shops; however, most fabrication is done by the manufacturers themselves (Gilman Insulation 1986b).

(2) Fabrication Process/Potential Exposure Points

Process Description and Automation. Essentially, fabrication shops are rooms with large work tables, onto which the blanket is unrolled and cut to specification. There is little to no automation in these shops. Workmen use mechanical shears to slice the blanket to its desired size. After the blanket is cut, the workmen manually stack the pieces and place them in large corrugated boxes for shipment (Gilman Insulation 1986b). Boards and vacuum formed shapes are usually trimmed using hand saws, followed by manual sanding and packaging (Esmen et al. 1979).

For applications in areas where the insulation has to be removed frequently (e.g., around valves and pipes), silicon or fiberglass jackets are placed around the ceramic blanket so the blanket is easily removed and reuseable. The ceramic blanket is encapsulated in a jacket which is sewn around the blanket with wire. Catches and hooks are also sewn on for installation purposes; some shops use velcro fasteners. All sewing is done by hand (Manville 1986b).

Engineering Controls and Protective Equipment. The range of ventilation systems used in fabrication shops varies greatly. Some shops use general ventilation (Manville 1986b), while others place large exhaust fans with dust collectors throughout the shop in addition to portable fans at the ends of the work tables to direct the dust (Gilman Insulation 1986b). Workmen wear respirators, coveralls, gloves, and eye protection in the shop (Gilman Insulation 1986a).

(3) Extent of Potential Exposure

Number of Persons Exposed. Between 4 and 25 workmen may be found in a fabrication shop, depending on both the size of the job and the size of the shop. The workmen have no discrete job functions; they do whatever needs to be done. Often times, in the case of insulation contractors, the same men who work in the fabrication shop also install the finished product (Gilman 1986b).

Respirability of Airborne Fibers. Monitoring data for an employee in the fabrication shop at C-E Refractories indicate a breathing zone fiber concentration of 0.03 fibers/cc. As is true for fabrication shops in general, the employee does not have a single job function. The duration of exposure was 6-3/4 hours (C-E Refractories 1986a).

Data on exposure during fabrication from the Head and Wagg (1980) study indicate airborne fiber concentrations between 0.09 and 0.87 fibers/cc (0.44 fibers/cc respirable average) for blanket fabrication and between 0.62 and 0.67 fibers/cc (0.65 fibers/cc respirable average) for the finishing of vacuum formed shapes using optical microscopy (see Table 10). Data in Table 11 indicate that 88-100 percent of the airborne fibers are respirable (i.e, have diameters less than 3.5 μm) (Head and Wagg 1980). Parallel sampling techniques were used to obtain airborne dust levels in terms of both the gravimetric concentration of total particulate dust and the concentration and size distribution of the fibrous fraction as determined by optical microscopy (Head and Wagg 1980).

Data on exposure during fabrication from the Esmen study indicate airborne fiber concentrations between 0.29 and 1.7 fibers/cc (0.74 fibers/cc average) for blanket fabrication and between 0.7 and 56 fibers/cc (7.6 fibers/cc average) for the finishing of vacuum formed shapes (see Table 9). Fiber concentrations as high as 56 fibers/cc were observed in areas where unventilated operations were performed (Esmen et al. 1979). Since the Esmen study was completed in 1979, a trend toward automation and increased usage of ventilation systems has been seen in the non-continuous refractory ceramic fiber industry (A.P. Green Refractories 1986).

d. Installation and Removal of Ceramic Fiber Products

(1) Contractors

There are between 50 and 75 insulation contractors in the U.S. (including Gilman Insulation, Insulation & Refractories Services, and Manville) who are involved in the installation of ceramic fiber blankets,

Table 10. Respirable Fiber Concentrations -- Non-Continuous Refractory Fiber Product Fabrication

Operation	Number of Samples	Average Respirable[a] Fiber Concentration (fibers/cc)	Range (fiber/cc)
Blanket Fabrication	9	0.44	0.09-0.87
Finishing Vacuum Formed Ceramic Moulding	2	0.65	0.62-0.67

[a] Respirable fiber is defined as ≤3 μm diameter and ≥5 μm long.

Note: Fiber concentrations determined using optical microscopy.

Source: Head and Wagg 1980.

Table 11. Overall Mean Values of Size Distributions for Airborne Ceramic Fibers During Product Fabrication

Operation	Diameter[a] (in μm by %)				Length[b] (in μm by %)		
	≤1	1-2	2-3	3-10	5-10	10-50	50-100
Blanket Fabrication	22	53	13	12	8	49	43
Finishing Vacuum Formed Mouldings	32	53	15	0	13	55	32

[a] For fibers up to 10 μm in diameter.

[b] For respirable fibers up to 100 μm long.

Note: Size distributions determined using optical microscopy.

Source: Head and Wagg 1980.

felts, papers, and boards. Each contractor employs between 25 and 200 people, of which only about 10 percent are actually involved in the installation of ceramic fiber products. In addition, only about 5 percent of each worker's time per year is spent installing ceramic fiber products (Gilman Insulation 1986b). Many companies, such as E.I. duPont de Nemours & Company (hereafter referred to as DuPont), have their own employees install ceramic fiber products (DuPont 1986c).

(2) Installation/Removal Methods

Installation and removal methods do not vary much between contractors. Three methods are generally used: the wallpaper method, the modular-veneering method, and the module linings with anchors method.

Wallpaper Method. Metallic anchors (for temperatures greater than 2250°F, ceramic anchors are used) are welded perpendicular to the furnace shell at regular intervals. The refractory fiber blanket is then pressed onto the sidewalls and ceiling of the furnace. The anchors pierce the blanket and hold it in place. The blanket is then secured with anchor washers. Boards, felts, and vacuum formed shapes may also be installed in this way (Gilman Insulation 1986b). A variation of this method is called stack construction; several layers are impaled onto the anchors instead of one (Cenedella 1982).

Removal is the reverse of installation. Workmen remove the washers from the anchors, and then simply remove the blanket off the nails (Gilman Insulation 1986b).

Modular-Veneering Method. The modular-veneering technique is used for the installation of refractory fiber blankets which have been prefabricated into modular units. These modular units serve as an alternative to stack construction. The modules are installed onto the furnace wall using refractory mortar (Cenedella 1982). Removal, in this case, means ripping the blanket off the furnace wall by hand (DuPont 1986c).

Module Linings with Anchors Method. An alternate method for installing modules is to use anchors instead of refractory mortar (Babcock & Wilcox 1986b). The anchors are welded onto the furnace using the same method as is used for blankets (i.e., the wallpaper method). As with the wallpaper method, removal is simply the reverse of the installation process.

Removable blankets (i.e., blankets which have been encapsulated with a jacket) require little time for installation. Most removable blankets have velcro fasteners or a catch and hook system; therefore, the blanket is simply wrapped around the valve, pipe, or other piece of equipment.

(3) Engineering Controls and Protective Equipment

Controls vary greatly between contractors. Refractory ceramic fiber products are installed in industrial areas where controls of some kind already exist. Some contractors rely solely on the controls present at a site, whether they be general ventilation, local ventilation, or even open air with no additional controls (DuPont 1986c). Other contractors bring in portable ventilation units (positive air devices or industrial grade fans). The usage of portable ventilation units over the last 3 to 5 years has increased significantly (Gilman Insulation 1986b). All contractors recommend to their employees that they wear respirators, gloves, disposable coveralls, and eyewear; however, usage of this equipment is optional.

The Thermal Insulation Manufacturers Association (TIMA) has issued a list of recommended guidelines for the installation and removal of ceramic fiber refractory products (see Table 12) (TIMA 1984). Most contractors have adopted these guidelines as work practices (DuPont 1986c).

Table 12. Recommended Health/Safety Work Practices for Installation and Removal of Ceramic Fiber Refractory Products

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Installation

- Wear long-sleeved, loose fitting gloves and eye protection.
- Use a disposable, NIOSH approved respirator for protection against nuisance dusts (3M Model 8710 or equivalent).
- Wash all exposed areas gently with soap and warm water after handling or other contact with the product.
- Wash work clothes separately from other clothing and rinse washing machine thoroughly after use.

Removal

- Respirators, such as 3M No. 8710 or equivalent, which are NIOSH approved for protection against pneumoconiosis producing dusts should be used.
- During removal or repair, the area being removed or repaired should be sprayed with water, preferably containing a wetting agent (detergent), to suppress dusting.
- Dust collection apparatus should be used.
- Protective clothing designed to minimize significant dust retention should be used and vacuum-cleaned prior to removal. Use of cotton and wool clothing, which tends to retain dust, should be avoided.
- Dustless methods of cleaning, such as wet vacuuming or washing down with water, should be used. Cleaning with compressed air blowing or dry sweeping should be prohibited. Light dust may be swept using dust suppressing sweeping compounds.
- Prior to removing furnace lining, each employee shall be apprised of the possible hazards and proper conditions and precautions for safe handling.
- Each employee shall be advised of the location of such information. Company "Material Safety Data Sheets (MSDS)" or generic MSDS, are acceptable for most applications.

Source: TIMA 1984.

(4) Potential for Exposure

Although no monitoring data are available for installation and removal of ceramic fiber insulation, it is known that airborne concentrations vary considerably. Concentrations may be as low as zero during the installation of removable blankets because the ceramic blanket is totally encapsulated. The highest potential for exposure to ceramic fibers would be during the removal of blankets and modules which have been installed using refractory cement; these blankets are literally ripped off the furnace wall by hand (DuPont 1986c).

In July of 1985, TIMA conducted a series of simulated installation and fabrication operations in Chicago. These operations were monitored to obtain rough data on fiber levels during usage by craftsmen. The simulations were conducted in two enclosed trailers in which TIMA tried to simulate the worst conditions (C-E Refractories 1986b). The workers were provided with respiratory protection, eye protection, and gloves while carrying out the work procedures.

In the first trailer, blanket material was removed from its cartons, unrolled, and cut into 4-foot strips which were applied vertically over the wall studs. These strips were subsequently removed and trimmed to 1-foot square pieces and then re-applied to the studs. This procedure was repeated 2-3 times for the duration of the sampling period (approximately 1-2 hours). In the second trailer, bulk fiber was removed from its box or bag, separated (i.e., pulled apart) by hand and transferred to separate cartons. The process continued for the duration of the sampling period (approximately 1-2 hours). Samples were collected following cleaning of the trailers to ensure that background fiber concentrations were minimal, and that no residual fibers from previously tested materials remained airborne.

Fiber counting was conducted on nucleopore filters collected as personal monitors (~2 l/min) (Ontario Research Foundation 1985). Preliminary data from the tests have been obtained and are shown in Tables 13 and 14. The data indicate that airborne fiber concentrations ranged between 4.1 and 9.5 fibers/cc. The mean fiber diameter measured between 0.7 and 1.4 µm, and the mean fiber length measured between 14 and 34 µm. Over 95 percent of the airborne fibers had diameters less than 3.5 µm, making them respirable (Ontario Research Foundation 1985).

B. Continuous Fibers

1. Fiber Production

a. Fiber Producers

Continuous ceramic fibers are produced in the U.S. by 3M and DuPont. DuPont is currently producing continuous ceramic fibers at their pilot plant in Wilmington, DE (DuPont 1986a). The primary use of the continuous fibers is in textiles. Table 15 lists each of the fiber producers, their plant locations, and general information on the fiber being produced.

b. Fiber Production Process/Potential Exposure Points

(1) Process Description and Automation

No information has been provided to us on the process used at 3M to produce the Nextel® fiber (3M 1986a); however, DuPont (1986a) provided information on their process. DuPont uses a slurry process (see Figure 3). The slurry process begins with the mixing of alumina and water in several enclosed kettles. The resulting slurry is then pumped to a spinerette where it is spun into a continuous fiber which is wound up onto a bobbin. The next part of the process is referred to as sintering. The fiber is unwound and passed through a high temperature flame (3300°F to 3500°F) to reduce its water

Table 13. Airborne Fiber Concentrations -- Installation Simulation Program

Sample	Total Fibers Counted	Total Fields (@ 500X)	Volume Sampled (ℓ)	Fiber Concentration (fibers/cc)
F615-4-E	422	9	130.2	9.5
H	401	8	178.5	7.4
J	401	14	186.9	4.1
L	400	12	138.6	6.4
M	409	7	189.0	8.2
O	421	7	212.2	7.5

Source: Ontario Research Foundation 1985.

Table 14. Size Distribution of Airborne Fibers -- Installation Simulation Program

	Fiber Diameter			Fiber Length			Aspect Ratio		
	Mean (μm)	Standard Deviation (μm)	Count	Mean (μm)	Standard Deviation (μm)	Count	Mean	Standard Deviation	Count
F615-4-E	0.7	0.6	422	15	18	422	27	29	422
F615-4-H	1.4	1.2	401	29	40	401	29	45	401
F615-4-J	0.9	0.6	401	16	20	401	21	24	401
F615-4-L	0.8	0.5	400	16	29	400	23	42	400
F615-4-M	0.9	0.6	409	14	14	409	19	20	409
F615-4-O	1.0	0.8	421	19	21	421	25	31	421
F615-4-Z	1.3	1.0	419	34	57	419	37	74	419

Source: Ontario Research Foundation 1985.

Table 15. Major U.S. Producers of Continuous Textile Ceramic Fibers

Company	Fiber Name	Plant Location(s)	Process
DuPont	FP	Wilmington, DE (pilot plant)	Slurry
3M	Nextel®	Menomonie, WI	NG*

* NG = Not Given.

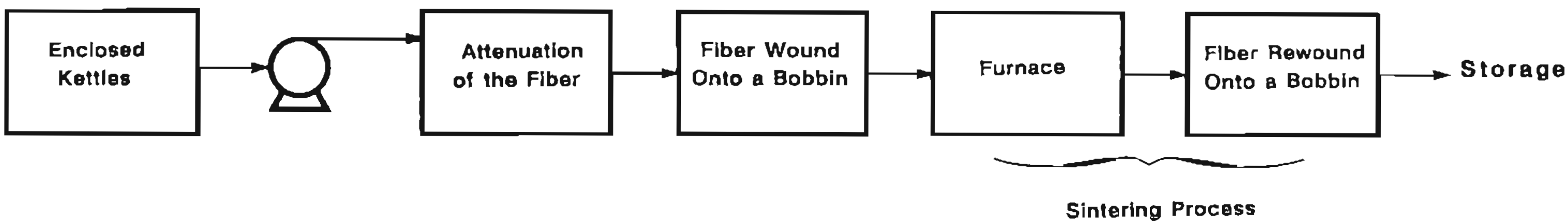

Figure 3. Primary process used by DuPont to produce FP fiber.

content. The fiber is then rewound onto a second bobbin and packaged (DuPont 1986a).

DuPont's process is almost fully automated and enclosed. Anytime an employee needs to move the fiber, he does so with a vacuum assisted sucker gun to avoid contact with the fiber. Five to six employees work on the line per one eight-hour shift; this figure includes one furnace operator who may oversee up to 10 furnaces, one employee in the area around the spinerette, and three to four others who move throughout the line (DuPont 1986a).

(2) Engineering Controls and Protective Equipment

Localized exhaust systems are used throughout the plant to control emissions. All employees are required to wear gloves and masks (DuPont 1986a).

c. Extent of Potential Exposure

(1) Number of Persons Exposed/Duration of Exposure

At DuPont, there are between five and six people working on a line at a time; the job functions are shown on Table 16. Each employee works an 8 hour shift on the line. The DuPont representative felt that the highest potential for exposure would occur during packaging. Monitoring data has been requested (DuPont 1986a).

(2) Respirability of Airborne Fibers

No information has been provided by 3M on the number of employees exposed (3M 1986a); however, monitoring data has been obtained for the plant. Industrial hygiene studies have been conducted at the 3M textile ceramic fiber production plant to determine the concentrations of airborne Nextel® fibers to which employees are exposed, and the physical characteristics (length and diameter) of the airborne fibers. Personal and general air samples were collected on open-faced type AA millipore filters and

Table 16. Number of Persons Exposed at DuPont's Continuous Textile Ceramic Fiber Production Facility

Number of Employees	Position	Function
1	Furnace Operator	Oversees 5-10 Furnaces
1	Operator by Spinettes	Oversees Several Spinning Wheels
3-4	Others	Maintenance Packaging Troubleshooting

Source: DuPont 1986a.

at an air intake of 2.5 liters/minute. The sampling times used were dependent upon the particular operation being monitored (up to 60 minutes). Phase contrast microscopy was used to determine fiber concentrations (3M 1986b). Airborne fiber concentrations vary between 0 and 0.0005 fibers/cc of air. The airborne fiber length varies between 20 and 6200 microns, and the fiber diameter varies between 9.3 and 37 microns (Larsen and McCormick 1980). Table 17 shows the results of this study. In general, airborne fiber exposure during the manufacture of continuous textile ceramic fibers is low, and the fibers are too large to be respirable.

Continuous fibers are of a large enough diameter and length to be considered nonrespirable. Their diameters are generally greater than 10 microns, and the lengths are essentially continuous. Short fibers are created as a result of a breakage of the continuous filament. Breakage is of a low enough incidence during manufacture to preclude any buildup of airborne fibers (Larsen and McCormick 1980). Additionally, the fibers are dense and, therefore, settle to the ground quickly making them unavailable for inhalation (DuPont 1986a). The industrial hygiene surveys conducted by 3M support this statement since airborne concentrations of ceramic fibers are very low (Larsen and McCormick 1980).

2. Fiber Use

Continuous ceramic fibers are available in cloth, tape, sleeving, rope, and braid forms. Like non-continuous refractory ceramic fibers, continuous ceramic fibers are used for high temperature applications (i.e., are refractory fibers); however, the potential for airborne emissions of continuous ceramic fibers is much lower than the potential for emissions of non-continuous ceramic fibers. Continuous fibers are very dense and, therefore, settle to the ground quickly making them unavailable for

Table 17. Monitoring Results for 3M Production Facility

Sample Description	Concentration Range (fibers/cc)	Range of No. Fibers on Filter	Range of Fiber Sizes (μm)	
			Length	Diameter
Area samples taken in fired fiber locations	0-0.0005	0-14	20-6200	9.3-37
Mean	0.0001	4.6	986	25.8

Note: Fiber concentrations determined using phase contrast microscopy.

Source: Larsen and McCormick 1980.

inhalation. In addition, the continuous fibers are of a large enough diameter and length to be considered nonrespirable. For these reasons, the discussion of ceramic fiber uses, and the corresponding potential for worker exposure, has been limited to the uses of non-continuous refractory ceramic fibers (see Section A.2).

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VI. ERIONITE FIBER

A. Fiber Production

Erionite, in its fibrous form, is a naturally occurring mineral fiber. Erionite is a hydrous silicate (i.e., silicon compound containing one or more water molecules) of calcium, potassium, sodium, and aluminum. The chemical formula is $(Na,K,Ca)_9(Al_9Si_{27}O_{72}).27H_2O$ (Albers 1981). Natural erionite occurs in abundance in sedimentary rock in the Southwest and Pacific Northwest regions of the United States (see Table 1). Erionite is one of a group of mineral fibers called the zeolites. There are about 40 distinct species of naturally occurring zeolites. Only two of the species, erionite and mordenite, always occur in fibrous form. The other species sometimes occur in fibrous form in certain deposits. Zeolites are also made synthetically; however, none of the synthetic zeolites are produced in fibrous form. Natural erionite does not have an exact synthetic counterpart. The synthetic zeolites have slightly different chemical composition, and molecular and geometric arrangements from their natural counterparts (ICF 1986).

Turkish erionite and its link to cancer have been investigated, but Norton determined that its own deposits of erionite were not similar to the suspect Turkish variety. Norton scientists determined through microscopic techniques that the erionite in their deposits is not fibrous in nature as is the Turkish erionite. The Norton representative claimed that the American erionite is structured differently and does not occur in long fibers (Norton 1986c).

1. Fiber Producers

The major roles in American natural zeolite production are filled by East-West Minerals, Denver, Colorado; Tenneco Specialty Minerals, Denver, Colorado; and Teague Minerals of Adrian, Oregon. These three companies all mine, produce, and sell zeolites on a regular basis (East-West Minerals

Table 1. Erionite Occurrences in Sedimentary Rocks

Locality	Zeolites
1. Near Durkee, Baker County, OR	Erionite
2. Near Rome, Malheur County, OR	Erionite, Mordenite, Phillipsite
3. Sheep Mountain Table, Shannon County, SD	Erionite
4. Pine Valley, Eureka County, NV	Erionite, Phillipsite
5. West Flank of the Shoshone Range, Lander County, NV	Erionite
6. Reese River, Lauder County, NV	Erionite
7. Jersey Valley, Pershing County, NV	Erionite, Phillipsite
8. Near Eastgate, Churchill County, NV	Erionite
9. Owens Lake, Inyo County, CA	Chabazite, Erionite, Phillipsite
10. Lake Tecopa, Inyo County, CA	Chabazite, Erionite, Phillipsite
11. Mojave Desert, Eastern Kern County and San Bernardino County, CA	Chabazite, Erionite, Mordenite, Phillipsite
12. Near Wikieup, Mohave County, AZ	Chabazite, Erionite, Phillipsite
13. Near Horseshoe Reservoir, Maricopa County, AZ	Erionite, Phillipsite
14. Near Bear Springs, Graham County AZ	Chabazite, Erionite, Phillipsite
15. Along San Simon Creek, Cochise and Graham Counties, AZ	Chabazite, Erionite
16. Bowie, AZ	Chabazite, Erionite

Source: Albers 1981.

1986). Currently these three major U.S. zeolite producers do not mine or produce erionite although they possess properties containing erionite ore. In fact, they do not even mine the other ores in their erionite-containing deposits (East-West Minerals 1986, Tenneco Minerals 1986, Teague Minerals 1986).

East-West Minerals recently acquired the zeolite property of the Anaconda Company near Rome, Oregon which is known to contain erionite ore. The Rome, OR property contains a two and a half foot layer of erionite sandwiched between two layers of mordenite. If East-West Minerals ever decides to mine the mordenite, it will remove the erionite to a waste dump. Spectrographic and microscopic analysis of the Rome deposit indicates that the mordenite present there is pure and free of erionite. The only natural zeolite that East-West presently mines is clinoptilolite from their Ashmeadows, CA property. This material is then shipped to Nevada for processing at East-West's plant (East-West Minerals 1986). Similarly, Tenneco Minerals has acquired the former Occidental Mining Corporation zeolite mines near Rome, OR from Phelps Dodge (East-West Minerals 1986).

Although Union Carbide and Norton are commercial miners and producers of natural zeolites, they are minor participants in the national sphere of natural zeolite production. Both maintain mine property in zeolite-rich Bowie, Arizona, but they very rarely actually mine these deposits. Likewise, both companies' processing operations are intermittent (East-West Minerals 1986).

Norton Company is the only company that recently supplied natural erionite based products. Norton manufactured erionite/chabazite mixed form powder and pellet products. Recently, Norton phased out its erionite operations because its erionite and molecular sieve markets are only a very small part of their business (Norton 1986b).

Some of Union Carbide's natural zeolite products may contain trace amounts of erionite, but none have erionite as a major component. Union Carbide could easily supply erionite commercially if a market existed for it, but other zeolites currently fill the existing demand (Union Carbide 1986a). Between 1970 and 1972, approximately 265,000 pounds of chabazite/erionite were mined by Union Carbide at Bowie, AZ (NIOSH 1981).

Table 2 identifies the companies that own zeolite deposits containing erionite. This data allows one to predict which companies may be involved in future erionite production should a demand for erionite develop.

2. Fiber Production Process/Potential Exposure Points

Although erionite is not currently mined, techniques used for mining and milling other natural zeolites would apply to mining and milling of erionite. This section discusses natural zeolites in general and not erionite specifically. However, if erionite were to be mined and milled in the future, the potential exposures would be similar to those found for other natural zeolites.

a. Process Description and Automation

(1) Mining

In identifying suitable deposits of zeolite, searchers drill test cores into rock until they locate beds with the desired purity and quantity of ore. The overburden is removed from suitable sites with scrapers and graders until the top of the ore bed is exposed. The top of the bed is carefully cleaned with picks, shovels, and a road broom; it is then blown clean with compressed air. A typical ore bed is planned to be 200 feet by 100

Table 2. Companies Possessing Erionite-Containing Zeolite Deposits

Company	Location of Deposit
East-West Minerals	Rome, OR
Tenneco Minerals	Rome, OR
Norton Co.	Bowie, AZ
Union Carbide	Bowie, AZ

Sources: Anaconda/ARCO 1986b, East-West Minerals 1986, Tenneco Minerals 1986b, Norton 1986b, Union Carbide 1986a, NL Industries 1986d.

feet and 20 to 50 feet below the surface ground (NIOSH 1981). Mining operations are very labor intensive, and most operations are manual.

Crews of six to 14 men remove the ore from the bed. Mining starts at the edges of the ore bed and goes toward the center of the deposit. Using a backhoe, the contractor breaks loose sections of the zeolite layer by positioning the bucket underneath exposed edges and lifting up. He then breaks up the large chunks with the backhoe while the laborers help with sledge hammers. The backhoe operator proceeds this way around the edge of the deposit while the other 5 to 7 workers pick up the broken pieces of ore and clean away any adhering soil with hand tools. The ore, once cleaned, is placed in a pile at the center of the pit. Laborers generally work an 8-hour day. At the day's end, the ore pile is loaded into a truck by machine and taken to a railroad siding for transport to crushing and processing facilities (NIOSH 1981). In the 1970's, the laborers at the Union Carbide mine worked from 4-6 months per year. There is no real continuity of employment because the work is intermittant (NIOSH 1981).

Mining of deposits that have no overburden may be done by a bulldozer equipped with a ripper. The ore is torn out of its bed, and, because the fresh ore is soft and contains approximately 30 percent moisture, it is left in long piles to air dry. The fresh ore may be soft and sticky. If so, it is often left to dry for months. Once dried, the zeolite is then crushed to a 6 inch size and stockpiled to allow for further air drying. All mining is done during the summer months. A loader and a dump truck serve to collect the stockpiled ore and haul it to the mill (Teague Minerals 1986).

(2) Milling

Natural zeolites (especially clinoptilolite) are processed in two ways: the dry process and the wet process. Figure 1 illustrates these

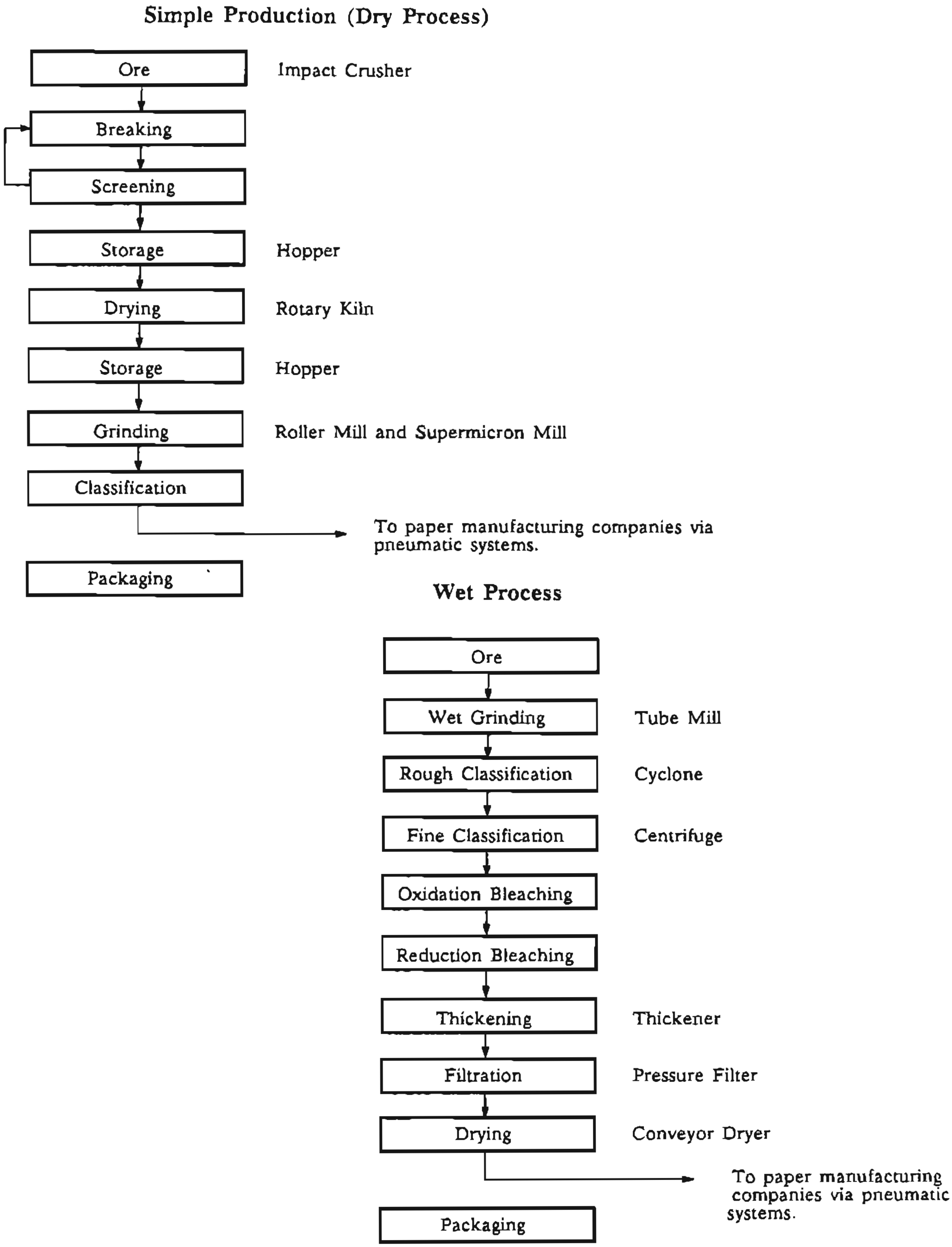

Figure 1. Zeolite milling processes. (Source: Sand and Mumpton 1978.)

two processes. No information on the level of automation or process enclosure could be obtained for these processes.

In the dry process, the ore is broken up with an impact crusher and screened; large pieces are returned to the crusher. Screened material goes into a hopper for storage before it is put through a rotary kiln for drying. Next, the zeolite is ground in roller mills and super micron mills. Classification is effected with a cyclone, and then the zeolite is packaged. The powdered zeolite is transported to paper manufacturing companies via pneumatic systems.

In the wet process, ore first goes through a wet grinding stage in a tube mill and is then rough classified using a cyclone. Fine classification is done in a centrifuge to separate the mixed zeolite ores. Next, impurities like ferrous oxide and organic materials are dissociated by oxidation bleaching and then by reduction bleaching. The zeolite is then thickened and filtered for purity. The filtered material is extruded into pellets, dried on a conveyer dryer, and then packaged (Sand and Mumpton 1978).

A Union Carbide representative reported that milling of erionite/chabazite involves grinding the ore to the appropriate size and then mixing it with a clay binder. This mixture is then extruded into pellets and finally dried in a kiln to set the clay (Union Carbide 1986a).

Although Teague Minerals does not produce erionite, a spokesman suggested that erionite is mined and milled using the very same methods that one would use to handle clinoptilolite, the most common and most versatile of the natural zeolites (Teague Minerals 1986). At the mill, standard grinding, screening, and air separation methods are used to reduce the ore to a powder. The same equipment used for milling clinoptilolite serves to reduce erionite and other natural zeolites. No dryers are used at the mill. The material has already been dried by exposure to air to the point where it is hard enough to grind properly; mechanical dryers could not do this efficiently. The 6-inch pieces of ore from mining are further broken up in a Raymond mill to a 1-1/2 to 2 inch size. Further grinding occurs in a 5057 Raymond mill to reduce the ore to grades at which it will be sold (Teague Minerals 1986). The Raymond milling machine contains a built-in air sizing device and a centrifuge sizer to separate the various grades of ground material. A silo stores the ground material until it is bagged by an automatic bagger or loaded into a pneumatic bulk truck via pneumatic systems (Teague Minerals 1986).

b. Engineering Controls and Protective Equipment

Zeolite mills are equipped with extensive dust control devices. There is generally no noticeable dust until the ore reaches the Raymond mills since the ore is not completely dry and is not dusty prior to that point. The Raymond mills are completely enclosed and under negative pressure so that there is no leakage of dust into the mill environment. The bagging machine is completely automatic; workers are not required to operate the machine or direct the flow of ground material. An employee need only load the machine with bags for filling and then stack them on a pallet. Dust is removed from the milled material by running the product through an aspirator. The aspirator draws clean air across the milled products as they are agitated by ripples in the conveyer and removes the dust that is knocked loose (Teague Minerals 1986).

Mine Safety and Health Administration (MSHA) approved dust masks are available for all employees, including maintenance personnel, and are worn by employees working near the bagging machinery. Positive pressure respirators are available, but their use is not required. The mill is kept well swept and free of standing dust by maintenance workers (Teague Minerals 1986).

3. Extent of Potential Exposure

a. Number of Persons Exposed

The entire zeolite (n.b., not erionite specifically) mining and milling operation at Teague requires 10 workers. One man using a bulldozer with a ripper can mine the ore. One man operating a loader and one driving a dump truck are able to collect and haul the ore to the mill. All milling procedures require only 7 workers (Teague Minerals 1986).

At Bowie, Arizona, 6 to 14 men are required to remove the ore from the bed. One man operates the backhoe, and the others use hand tools (NIOSH 1981).

b. Duration of Exposure

All mining by Teague is done during the summer months. The ore is stockpiled for use later in the year. Mill employees work a typical 40 hour week year round (Teague Minerals 1986). In addition to the five to ten thousand tons of zeolite that are milled during the course of a year, this mill is also used for milling bentonite clay.

Laborers at Bowie, Arizona generally work an 8 hour day for 4-6 months per year. There are no lifetime/career miners of zeolites because the work is intermittant. Most workers are primarily agricultural laborers (NIOSH 1981).

c. Respirability of Airborne Fibers

Monitoring data on mining operations collected during NIOSH's site visit to Union Carbide's erionite-containing zeolite deposit indicated that workers were not exposed to total or respirable particulate material in excess of legal or recommended exposure limits. Specifics of this study are presented in Tables 3 through 5 (NIOSH 1981); Figure 2 indicates the sampling locations. Table 3 presents results of personal air sampling, and Table 4 presents results of area sampling. In general, airborne particulate exposures are well below the Mine Safety and Health Administration (MSHA) and OSHA

Table 3. Laborer's Personal Exposures to Total Particulate Material[a]

Sample Number	Sample Period (min)	Concentration[b] (mg/m^3)	Remarks
002M	335	2.23	Working Upwind
003M	135	5.76	Working Downwind
005M	237	1.35	Working Downwind
008M	336	0.43	Working Upwind
009M	337	1.90	Working Downwind
012M	271	2.46	Working Downwind
013M	205	2.16	Working Downwind
014M	103	1.39	Working Downwind

[a] All samples collected on Millipore matched-weight 0.8m mixed cellulose ester (MCE) filters, with open-face cassettes. These samples were prepared and analyzed using NIOSH Method P & CAM 239 for asbestos fibers in air. Samples were analyzed using phase contrast optical microscopy at 400X magnification.

[b] Concentrations are for single samples.

Source: NIOSH 1981.

Table 4. Concentrations of Total and Respirable Particulate in Mining Area

Sample Number	Sample Period (min)	Concentration[e] (mg/m^3)	Remarks
004M[a]	172	13.69	Open-face MCE filter, total, downwind
2348[a]	138	2.60	Closed-face PVC filter, total, downwind
2332[a]	130	0.59	Cyclone, PVC filter, respirable, downwind
006M	324	0.55	Open-face MCE filter, total, upwind
010M[b]	292	0.03	Open-faced MCE filter, total, upwind
2339[b]	302	0.01	Closed-face PVC filter, total, upwind
011M[c]	155	4.77	Open-face MCE filter, total, downwind
2353[c]	272	0.41	Cyclone, PVC filter, respirable, downwind
001M[d]	394	1.26	Open-face MCE filter, total, tractor
2319[d]	394	1.01	Closed-face PVC filter, total, tractor
2336[d]	394	0.17	Cyclone, PVC filter, respirable, tractor
2342	138	1.36	Cyclone, PVC filter, respirable, downwind
2311	118	0.71	Closed-face PVC filter, total, downwind
2322	132	0.01	Cyclone, PVC filter, respirable, upwind

a, b, c, and d designate sets of samples collected side-by-side for comparison of total and respirable particulate.

[e] All samples collected on Millipore matched-weight 0.8m mixed cellulose ester (MCE) filters, with open-face cassettes. These samples were prepared and analyzed using NIOSH Method P & CAM 239 for asbestos fibers in air. Samples were analyzed using phase contrast optical microscopy at 400X magnification.

Source: NIOSH 1981.

Table 5. Summary of Optical Microscopy -- Air Samples from Pit 185

Sample Number	Microscopist's Description
001M	Heavy particulate, no fibers
002M	Medium-heavy particulate, no fibers
003M	Heavy particulate, small number of fibers
004M	Heavy particulate, no fibers
005M	Moderate particulate, no fibers
006M	Moderate particulate, no fibers
008M	Moderate particulate, no fibers
009M	Heavy particulate, small number of fibers
010M	Light particulate, no fibers
011M	Heavy particulate, small number of fibers
012M	Medium-heavy particulate, small number of fibers
013M	Heavy particulate, small number of fibers
014M	Moderate particulate, no fibers
Blank	No particles observed

Source: NIOSH 1981.

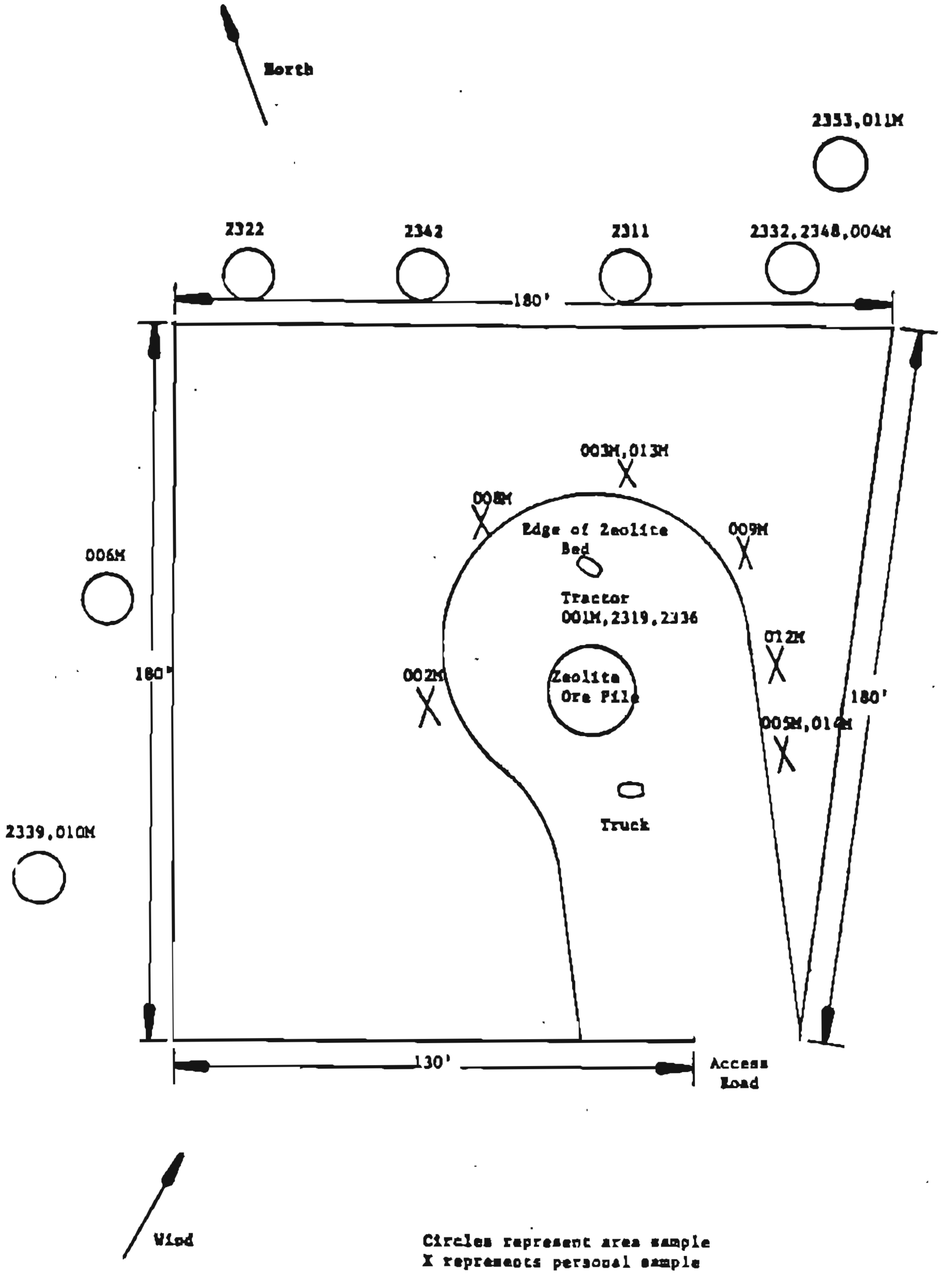

Figure 2. Sampling Locations -- Zeolite Pit No. 185. (Source: NIOSH 1981.)

enforceable standards for respirable nuisance dust of 5 mg/m^3. However, one personal air sample and two area samples all of which were taken downwind of the mine approached or exceeded this standard. Note, however, that these are total dust results which are allowed to be as high as 10 mg/m^3 (MSHA) or 15 mg/m^3 (OSHA). Area samples of total and respirable particulate material show that respirable particulate matter comprise 0.4 to 33 percent of total airborne particulate collected. As expected, Table 5 indicates that the highest airborne particulate and fiber levels are experienced downwind of the zeolite ore mine.

Phase contrast optical microscopic examination of airborne particulate material and bulk samples collected at the mining site indicated that the air samples contained irregularly-shaped particles of 1-10 µm in diameter, and only a very small number of fibers (in 5 of 13 samples). Examination by transmission electron microscopy (TEM) with energy dispersive X-ray analysis (EDXRA) and selected area electron diffraction (SAED) determined that the irregularly shaped particles were composed of Al, Si, K, Ca, and Fe, while the fibers showed only a peak for sulphur by EDXRA. Hence, the airborne fibers were not erionite fibers (NIOSH 1981).

The bulk samples of ore, overburden, and clay contained a very small number of fibers: one fiber that was 0.5 µm in diameter and 3.5 µm in length, and contained Al, Si, Fe, Ca, and K in the ore; one fiber that was 0.6 µm in diameter and 6.7 µm in length and contained Si, Mg, Ca, and Fe in the overburden; and four fibers in the clay, of which two were chrysotile asbestos (a possible laboratory contaminant) and the other two contained Si, Al, and traces of Ca, Fe, and Na. This microscopic and elemental analysis of air and bulk samples indicated that workers mining zeolite ore from Pit 185 on the survey day were not exposed to fibrous zeolite, and fibrous zeolite was absent or present in only very small traces in the ore, clay, and overburden (NIOSH 1981).

Only two fibers with elemental composition like erionite were found in all of the samples taken. Recall that this mine contains primarily non-fibrous chabazite which is the desired product. Fibrous erionite is an impurity sometimes found in chabazite.

Table 6 presents data gathered by MSHA on the exposure of laborers to respirable dust and quartz at Union Carbide's Bowie, AZ zeolite mine. Worker exposure to these materials is far below regulated limits. The respirable dust exposure was 0.31 mg/m^3 compared to a limit of 5.0 mg/m^3. Quartz exposures ranged from 0.16-0.47 mg/m^3 compared to exposure limits of 2.05-3.03 mg/m^3; exposure limits vary depending on the quartz concentration.

Erionite and mordenite are the most similar zeolites in physical dimensions to asbestos. Erionite is needle-shaped, and the needles are 10-20 μm in length and about 0.5-1 μm wide (Futgaki et al. 1978). The fiber dimensions of natural erionite vary with the particular deposit. Erionite fibers from a deposit near Eastgate, Nevada were found to be 2 microns in diameter and 10 microns in length. Fiber samples taken from an erionite deposit north of Rome, Oregon were found to have sizes ranging from 0.02 to 3.0 microns in diameter and from 0.5 to 60 microns in length (Albers 1981). In general, natural erionite fibers are of a respirable size.

B. Potential Fiber Use

Commercial applications of natural zeolites include: ion exchange, adsorption, molecular sieve phenomena, dehydration, and rehydration. Natural zeolites are used in the production of pozzuolanic cements and concretes, dimension stone, and light weight aggregate; as filler in paper; in ion exchange processes and air separation processes; as carriers for dietary

Table 6. Mine Safety and Health Association Monitoring Data for Union Carbide's Bowie, AZ Erionite-Containing Zeolite Mine

Date	Sample Location	Job	Respirable Concentration (mg/m³)	MSHA Exposure Limit[a] (mg/m³)
	EXPOSURE TO NUISANCE DUST, RESPIRABLE FRACTION			
05/26/82	Surface, Active Mining	Laborer (Bull gang)	0.31	5.00
	EXPOSURE TO QUARTZ, RESPIRABLE FRACTION, ≥ 1% QUARTZ			
05/26/82	Surface, Active Mining	Laborer (Bull gang)	0.16	2.30
05/26/82	Surface, Active Mining	Laborer (Bull gang)	0.66	3.03
05/26/82	Surface, Active Mining	Laborer (Bull gang)	0.47	2.05

[a] Exposure limits vary with quartz concentrations.

Source: MSHA 1986.

supplements for swine and poultry; in agricultural fertilizers to control the release of cations; and for drying and purifying acidic gases. Newer applicatons include use in solar powered refrigerators and in solar collectors that heat in the winter and cool in the summer. Four 300 liter columns packaged with zeolites are used at the Three Mile Island nuclear power plant to remove the bulk of the principal radioactive isotopes from contaminated water (Albers 1981, Union Carbide 1986a). One known erionite-rich zeolite deposit, located near Rome, Oregon, is quarried for dimension stone; a few hundred tons of impure erionite-rich rock is cut into facing stone each year for local consumption. A Union Carbide representative claims that there are 50-70 types of products that are made from natural zeolites (Union Carbide 1986a).

Although in the past ten years erionite was often used in molecular sieves, ion exchange, and oil refinement, no current use is found for this zeolite. Other zeolites such as clinoptilolite and synthetic zeolites are now more popular for these uses and are actively mined and manufactured. These other zeolites perform the same processes as erionite and are not considered a health risk. Perhaps in the future, erionite will regain popularity if a use is found that suits its unique physical and chemical properties. Therefore, the processes and potential exposure points for these operations, based on information for other zeolites, are presented as surrogates for potential future exposure to erionite.

Given that research and development efforts into commercial uses for natural zeolites are only now beginning to receive focused attention in the United States and that little of this effort is directed towards erionite specifically, the current demand for erionite, at least in the near future, will probably not change. Therefore, discussions of manufacturing processes and potential exposures during its use are based on the assumption that they would be handled like other zeolites used in the same applications. In general, the discussions below present information on zeolites other than erionite.

1. Molecular Sieves

In the petrochemical industry, zeolites are used to separate, dry, and purify chemical products. Zeolites are used in the separation of raw gas from crude oil. Oil fed through a zeolite-packed column is relieved of its raw gas which is adsorbed by the zeolite. In the drying processes for hydrochloric acid, chlorine, reformer hydrogen, and petroleum solvents, zeolites adsorb water molecules. Reformer hydrogen, chlorine, and chlorinated hydrocarbons may be purified of hydrochloric acid by zeolites packed into reacting vessels (Futgaki et al. 1978).

Between 1970 and 1972, approximately 264,500 pounds of chabazite/erionite mixed zeolite (n.b., erionite is only considered a contaminant in the chabazite and is probably contained in low concentrations) were sold by Union Carbide from their Bowie, AZ deposit, under the tradename AW-500®, to be used as a molecular sieve for removing hydrochloric acid from reformer hydrogen streams, water from chlorine, and carbon dioxide from stack-gas emissions (ICF 1986).

Erionite can also be used to remove SO_2 and CS_2 contaminants from hydrocarbons (Sand and Mumpton 1978).

a. Manufacturers

Union Carbide makes two natural zeolite products called AW-300 and AW-500; these molecular sieves find use in applications involving contact with gases or liquids that are very acidic. The natural zeolites used in AW-300 and AW-500 are more acid-resistant than the synthetics Type A and Type X.

The buyers of these two products tend to be in the natural gas industry. These AW products serve to dehydrate and purify sour natural gas (i.e., gas that contains SO_2 and H_2S as contaminants. These molecular sieves are also useful in removing HCl from chlorinated hydrocarbon stocks (Union Carbide 1986b) and in drying reformer recycle hydrogen.

At one time, the Norton Company produced a line of products called the Zeolon Molecular Sieves. The Zeolon 500 series of this line was based on a chabazite/erionite ore. This Zeolon product line was discontinued several years ago because Norton decided to phase out its molecular sieve business which was only a small part of its overall business. Large commercial quantities of Zeolon 500 were never sold. Only two reactor loads of Zeolon 500 were ever marketed.

b. Manufacturing Process/Potential Exposure Points

At Union Carbide the zeolite material (chabazite/erionite) is first ground to the appropriate size and filtered. Next, the zeolite filter cake and a wet clay binder are mixed thoroughly. The clay and zeolite mixture is then extruded into pellet form. The clay is set by heating the pellets in a kiln. This heating also activates the zeolite by removing the moisture in the pellets. The pellets are loaded into drums for shipping. In use, the pellets are poured into cylindrical columns in a packed bed system (Union Carbide 1986b). Union Carbide's representatives were unwilling to discuss details of the manufacturing process, number of workers, duration of exposure, areas of exposure, engineering cotrols, or protective equipment associated with their operations.

2. Catalysts

Zeolites are useful in the catalytic operations of hydrocracking, hydroisomerization, alkylation, and reforming in the petroleum industry. The zeolites are first processed by combining with a clay base or other catalysts before introduction to the catalytic reactor. The zeolites provide more surface active sites for reactions during the cracking reaction than do noble metal catalysts unimpregnated onto a carrier (Futgaki et al. 1978).

Erionite adsorbs n-parrafins and excludes iso-parrafins; hence, it was used widely by oil companies as a shape selective hydrocarbon-conversion catalyst for cracking of n-parrafins to yield C_1 to C_3 products. Erionite is most effective on hydrocarbons shorter than nine carbons and longer than twelve carbons. Mobil's "Selecto-forming" process used noble metal-impregnated erionite to hydrocrack C_5-C_9 n-parrafins down to their C_1 to C_3 components; this process boosted the octane rating of the fuel (Sand and Mumpton 1978). Currently Mobil manufacturers synthetic zeolites like the analogs of faugicite, zeolites X and Y to perform these refining catalyst duties (Mobil Oil 1986).

a. Manufacturers

Mobil Oil no longer uses erionite in commercial oil processing. They use no materials with aspect ratios greater than 3:1. Mobil's Selecto-forming process went into use in 1968 and involved an erionite/noble metal catalyst. This processing technique was phased out of use approximately 10 years ago. Mobil now manufactures synthetic zeolites to perform these catalyst functions. The synthetics are analogs of faugicite (e.g., zeolites X and Y) (Mobil Oil 1986).

Mobil uses no natural zeolites in commercial processes. Their fibrous nature, impurities, and necessary secondary processing for contaminant removal make them impractical. The synthetic zeolites yield better refining properties (Mobil Oil 1986).

The Mobil spokesman believes that no companies currently use erionite in refining because of the liability that they could incur. A compilation of the Proceedings of the International Zeolite Conference (July 1983) does not contain any papers on erionite (i.e., there is little activity in erionite research and development) (Mobil Oil 1986).

NC-300 is currently the only natural zeolite product that Norton Company manufactures. NC-300 is an ion exchange catalyst used in the selective reduction of NO_x, with ammonia serving as the reducing agent. This product is used in power plants, gas and diesel engines, industrial boilers and process heaters, refineries and petrochemical plants, chemical processing plants, cement and glass works, refuse incineration units, and nuclear waste treatment. NC-300, however, contains no erionite (Norton 1986b, 1985).

b. Manufacturing Process/Potential Exposure Points

The non-erionite containing zeolite found in NC-300 is mined and milled by another company which supplies Norton with a 325-mesh grade powder. Presently, workers slit bags of the powdered zeolite and pour the zeolite into a hopper which feeds into a reactor where it is mixed with water, and an ion exchange process is carried out. The contents of the reactor are centrifuged and dried. Next, an alumina binder is added and the product is extruded into rings, stars, and honey combs. This manufacturing method is not large scale and is only temporary (Norton 1986c).

A manufacturing plant expected to be on-line in late June of 1986 will use an enclosed pneumatic system to unload hopper trucks of powdered zeolite into bins. The zeolite will then be transported to the reactor pneumatically. After the addition of water and the ion exchange reaction, the reacted zeolite will be pumped into a filter press. The reacted zeolite leaves the press as a filter cake that still contains 30 percent moisture. For some applications, the product may be used as is. For other applications, the filter cake is dried and proceeds to a hammer mill for crushing; the crushed zeolite is stored in a bin. The contents of the bin are mixed with binder and extruded (Norton 1986c).

Exposure to dust could occur in two places -- bulk truck unloading area and the dryer/crusher area. Both of these areas have baghouse collectors for dust removal. Once extruded, there is little potential for airborne zeolite fibers. When the catalyst has lost its effectiveness, it may be ground up and buried in a sanitary landfill (Norton 1986c).

c. Extent of Potential Exposure

The Norton system is completely automated. One worker may run the entire operation from a glassed-in control booth. Since the operator is isolated from the process, personal protection is not required. The plant will run two shifts per day, year round. Maintenance is unnecessary unless there is a problem like a spill or malfunction. Maintenance workers will be required to wear dust masks (Norton 1986c).

3. Environmental Uses -- Ion Exchange for Wastewater Treatment

Zeolites offer great potential for a wide variety of wastewater treatment applications. Currently, these uses remain limited to treatment of municipal wastewaters for ammonia removal, and removal of radioactive nuclides from contaminated waters by several government and private nuclear facilities. Zeolites can selectively scavenge low levels of heavy metals, radioactive nuclides, and ammonia from water and air (Teague Minerals 1985).

Zeolites, including erionite, may be used to treat and dispose of radioactive wastes because of their affinity for cesium ions. Zeolites can be used to remove cesium-137 from high-level radioactive wastes, decontaminate low and intermediate-level radioactive wastes, and fix radioactive wastes for long-term storage. These same zeolites may also be used to remove ammonium ions from wastewater. This type of filtering helps municipal wastewater treatment plants bring ammonia nitrogen to levels permitted by local regulations (Sand and Mumpton 1978, Futgaki et al. 1978).

a. Manufacturers

The Tahoe-Trucker Sanitation District wastewater plant uses clinoptilolite, a zeolite, in a completely enclosed pressure filter for wastewater treatment. Clinoptilolite removes ammonium ions from the treated water (Tahoe-Trucker 1986).

During the summer of 1982, the Upper Occoquan Sewage Authority, located in Centerville, VA, operated a plant for five to six months that made use of ion exchange columns filled with clinoptilolite for the removal of ammonium ions from wastewater. After those months, the system was shutdown because it was not cost effective. As a nitrogen removal system it was not as effective as other processes at the plant's disposal (Upper Occoquan 1986).

b. Manufacturing Process/Potential Exposure Points

Tenneco Specialty Minerals mines and markets clinoptilolite primarily. They own deposits of erionite but do not produce or market it. Tenneco's zeolite milling process is very similar to that used by Teague Minerals. The zeolites produced for environmental uses are generally used in ion exchange columns. These large vessels (40' height x 10' diameter) are usually filled at the sites where they are to be used. Many installations such as wastewater treatment plants fill the columns themselves (Tenneco 1986).

Tenneco sells zeolites to facilities in 50 lb. bags or 2,000 lb. bags for addition to the ion exchange columns. From the information obtained, it appears that the zeolite may be used directly from the mill without any treatment of modification prior to use in wastewater treatment applications. In the case of some sewage treatment plants, the zeolite is sold directly to the user facility. In other cases, an intermediate company may provide the service of obtaining zeolites and loading the columns. An example of such an intermediate company is Chem Nuclear in South Carolina, a division of Waste Management (Tenneco 1986).

Chem Nuclear handles sluicable demineralization equipment. They load ion exchange vessels by pumping water and suspended material into them. When the zeolite has lost its desired properties, they sluice the exhausted, reacted zeolite out of the column for disposal.

The crushed zeolite may come in a container through which water is pumped to load the reaction vessel. This is an automated procedure in which human exposure is minimal. If the zeolite comes in bags, workers must break open the bags and shovel the contents into hoppers. The workers then sluice the contents of the hopper into the reaction column. When the column's contents are exhausted of their sieving abilities, the sealed column is sluiced into another large liquid container. A polymer is added to the discarded material to effect solidification. Chem Nuclear then buries this solid mass in a radioactive waste disposal site. The entire disposal system is sealed (Chem Nuclear 1986).

Workers that shovel the zeolite material into the hopper wear paper respirators that are nuclear qualified. These are not self-contained breathing devices. Workers also wear gloves. There are no engineering controls to protect the workers (Chem Nuclear 1986).

Every five to seven years at the Tahoe-Trucker treatment plant, the ion exchange filters are cleaned out and rebuilt with fresh zeolite. In the past, the zeolite was unloaded from sacks and shoveled into the filters dry. More recently, the zeolite has been flushed into the filters as a slurry. No engineering or personal precautions are taken when using clinoptilolite. Used zeolite is discarded on a field to condition the soil (Tahoe-Trucker 1986).

c. Extent of Potential Exposure

Chem Nuclear supplies DOE and defense facilities with ion exchange columns to clean up radioactive waste ponds. They buy approximately 1/2 of a truckload of zeolite per year from Phelps Dodge. DOE uses less than a 40 foot truckload of zeolite each year. Mixed bed resins are frequently used in the same applications. DOD supplies zeolite to Chem Nuclear for loading into columns.

Although a lot of zeolite columns were used to clean up wastewater generated at the Three Mile Island Nuclear Power Plant, zeolite columns are not the most popular method for this type of work. Only a small amount of zeolite is purchased for handling radioactive waste. When manual loading of columns is necessary, the work of one man for three days each year fulfills the labor requirement. Other companies in the demineralization business, Duro-Tech and Hitman Nuclear, use beads and mixed bead resins rather than zeolites (Chem Nuclear 1986).

The workers at the Tahoe-Trucker plant handle the clean out and reloading procedures themselves. The entire operation takes two to four weeks of two laborers working eight hours per day. There are five filter columns that must be maintained in this manner (Tahoe-Trucker 1986).

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VII. FIBERGLASS

Fiberglass is glass which is produced in fibrous form. Fiberglass is produced in two basic forms, as a short-length monofilament or as a continuous strand composed of many monofilaments. The former is referred to as "fiberglass wool" or "insulation fiber" (the primary use of fiberglass wool is in insulation). The latter is referred to as "textile fiber" or "continuous filament".

The processes used to manufacture fiberglass wool differ greatly from those used in the production of textile fiber. Industry and literature sources indicate that the potential for exposure to respirable glass fibers is much lower in the production of textile fiber than in the production of fiberglass wool (Owens-Corning 1986a, Certain-Teed 1986a, Esmen et al. 1979, NIOSH 1977). The lower exposure potential in textile fiber production is a result of the larger nominal fiber diameter and the narrower diameter distribution of the textile fibers, the higher level of automation, and the earlier application of binder in textile production, as compared to fiberglass wool production. This report will discuss primarily fiberglass wool and wool products. Textile fiber production and uses will be discussed in less detail since the exposure potential is expected to be lower.

A. Fiber Production

1. Fiberglass Wool

The production of fiberglass wool is not easily separated from the production of fiberglass wool products. The production of thermal insulation for residential use, for example, is a continuous process in which the fiberglass wool is spun from the glass melt, collected on a conveyor, and processed into the insulation product, which is then removed from the production line for packaging or further processing. Consideration of the production of fiberglass wool independently of the production of fiberglass wool products does not adequately account for the continuity of the production process, nor does it account for the maintenance personnel who must service all the machines, not just those directly related to fiberglass wool production. Therefore, fiberglass wool production plants (those which produce fiberglass wool from the glass melt) will be considered as fully integrated insulation production units. Some specialty products manufactured at these facilities (e.g., pipe insulation) will be discussed as well as high volume products (e.g., residential insulation).

a. Fiber Producers

Fiberglass wool is manufactured by five companies at a total of 26 locations in the U.S. Table 1 shows the location of and total employment at each plant (ICF 1986). Manufacture of insulation products is the major use of fiberglass wool.

b. Fiber Production Processes/Potential Exposure Points

Fiberglass wool is produced by one of two processes: the rotary spin (RS) process and the flame attenuation (FA) process. The RS process was developed in the 1950's, and since that time has substantially replaced the FA process. According to EPA, the FA process contributed less than 20 percent of the total wool fiberglass production in 1980 (EPA 1983).

Production of fiberglass wool involves the following process steps:

- Production of molten glass;
- Formulation of fibers from molten glass;
- Application of binder to fibers;
- Formation of fiberglass mat from binder-coated fibers;
- Curing and compression of mat;
- Cooling of mat;
- Application of backing;
- Cutting/trimming; and
- Rolling/packaging.

Table 1. Manufacturers of Fiberglass Wool

Company	Plant Location	Number of Employees at Plant Site
Certain-Teed	Athens, GA	370
	Berlin, NJ	300
	Kansas City, KS	521
	Mountaintop, PA	379
Guardian Industries, Inc.	Albion, MI	200
	Northville, MI	80
Knauf Fiber Glass	Shelbyville, IN	500
Manville Corporation	Berlin, NJ	N/A
	Cleburne, TX	390
	Corona, CA	300
	Defiance, OH[a]	700
	Defiance, OH	350
	McPherson, KS	400
	Richmond, IN	386
	Vienna, WV	400
	Willows, CA	330
	Winder, GA	500
Owens-Corning Fiberglas	Anderson, SC[b]	1,000
	Barrington, NJ	850
	Delmar, NY	450
	Fairburn, GA	600
	Kansas City, KS	800
	Mount Union, PA	111
	Newark, OH	2,200
	Santa Clara, CA	1,000
	East Waxahachie, TX	600

[a] There are two Manville plants located in Defiance, OH.

[b] Both fiberglass wool and textile fiber are produced at this plant.

Source: Dun's Market Identifier 1986, USDOC 1985.

A process flow diagram is presented in Figure 1. The process steps are illustrated schematically in Figure 2. Many different types of fiberglass wool products can be manufactured using the same process line. For example, one plant produces 15 different fiberglass product groups (500 different products) using six production lines (Manville 1986, NIOSH 1984). Production of different products requires changes in the process parameters and/or production steps. Pipe insulation manufacture requires two additional process steps between the mat formation and curing steps, as illustrated in Figure 1. Production of blowing wool can either be directly from the fiberglass wool or from reclamation of insulation product trimmings (NIOSH 1977, Knauf 1986, Certain-Teed 1986c). These process steps are also illustrated in Figure 1.

(1) Process Description and Automation

Basic Fiberglass Wool Production. Fiberglass wool is produced by either the rotary spin (RS) or flame attenuation (FA) process. These processes are illustrated schematically in Figures 3 and 4, respectively. In the RS process, molten glass flows from the furnace forehearth into the center of a rapidly spinning perforated rotor. The glass is drawn through the perforations and forms fibers which are attenuated (blown off) by high velocity airjets around the outside of the rotor. Typically, there are two to twelve spinners on a single fiberglass line (Pundsack 1974, Smith 1974, EPA 1983).

In the FA process, coarse (30 mil) primary filaments are formed by drawing molten glass from glass melting pots through platinum alloy bushings. These filaments flow in front of high pressure high velocity gas jets, which attenuate them into fibers. Typically there are six to twenty-eight melting pots per line (Pundsack 1974, Smith 1974, EPA 1983).

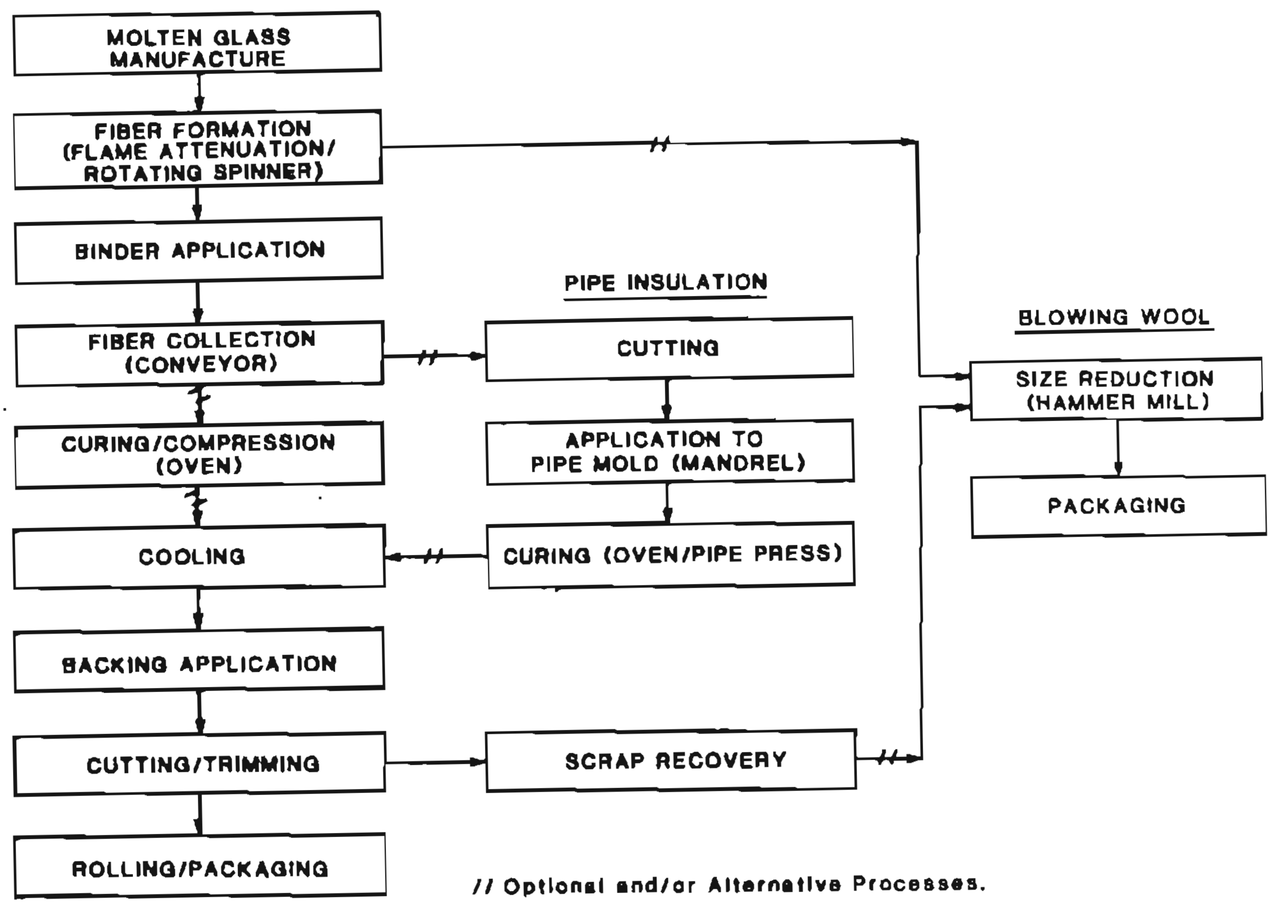

Figure 1. Fiberglass production process -- wool manufacture, residential/ commercial and pipe insulation.

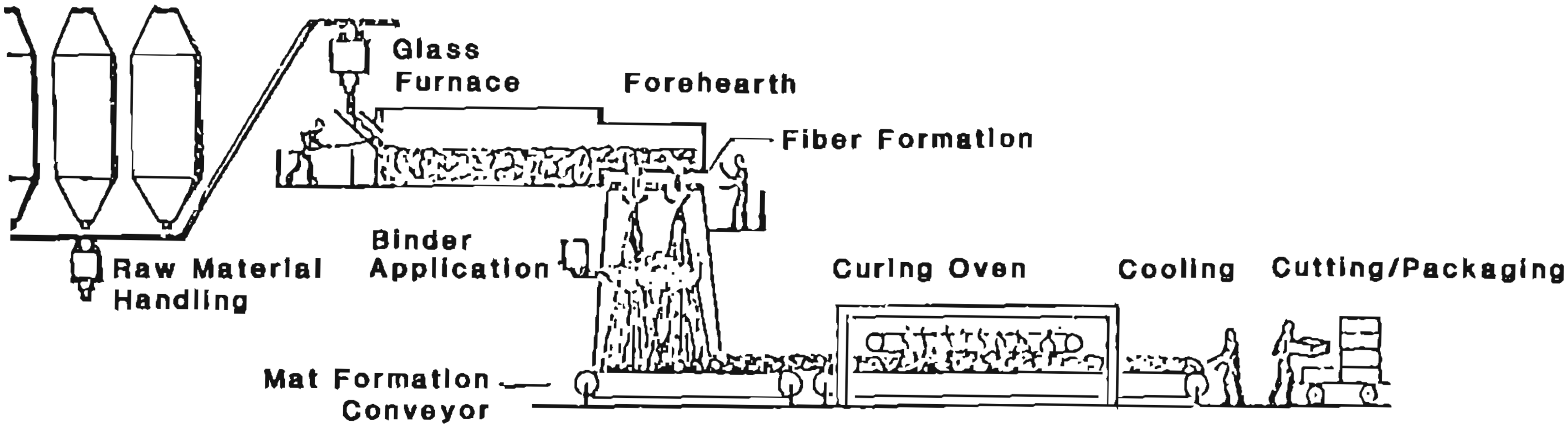

Figure 2. Fiberglass wool manufacturing process.

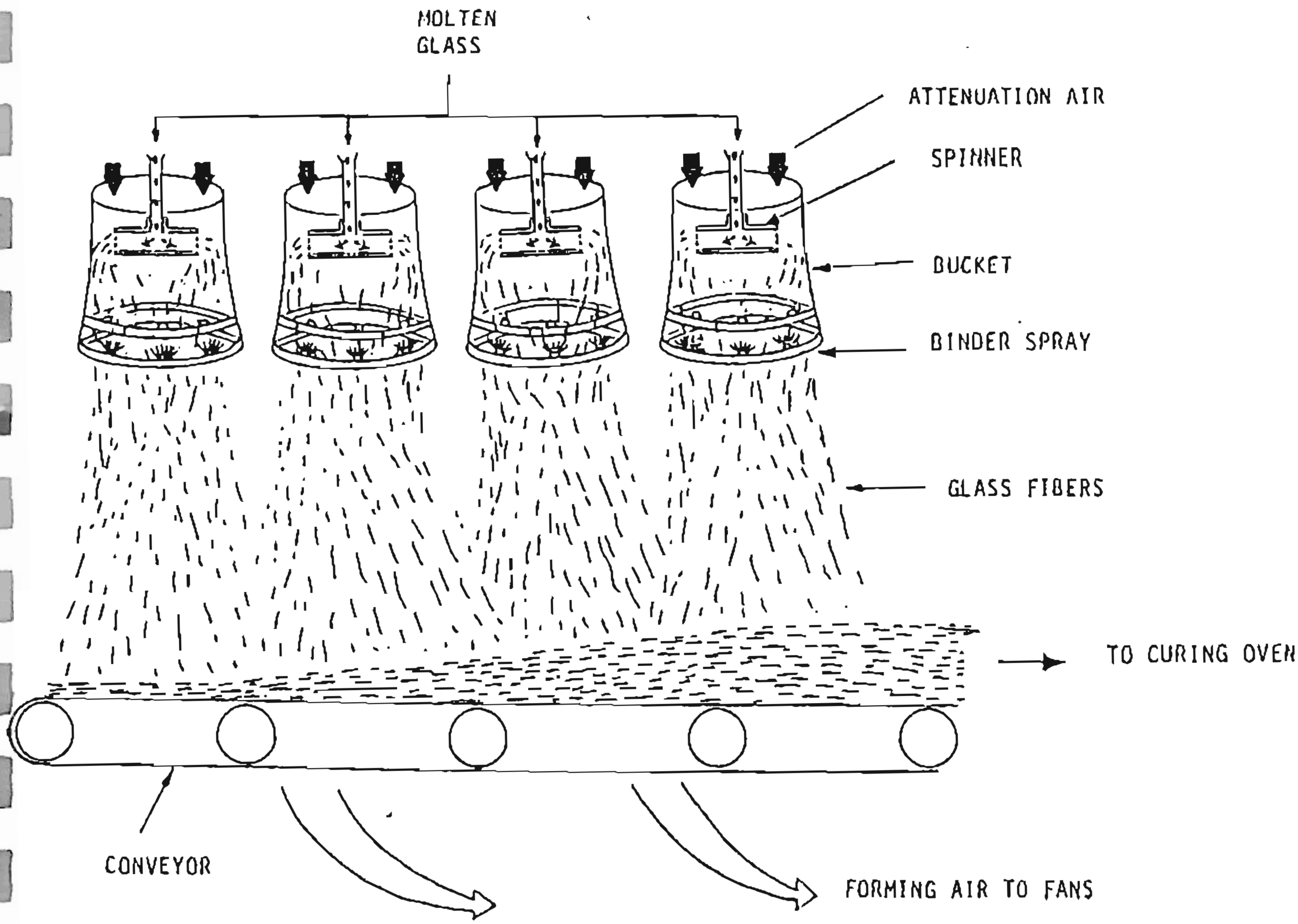

Figure 3. Rotary spin process. (Source: EPA 1983.)

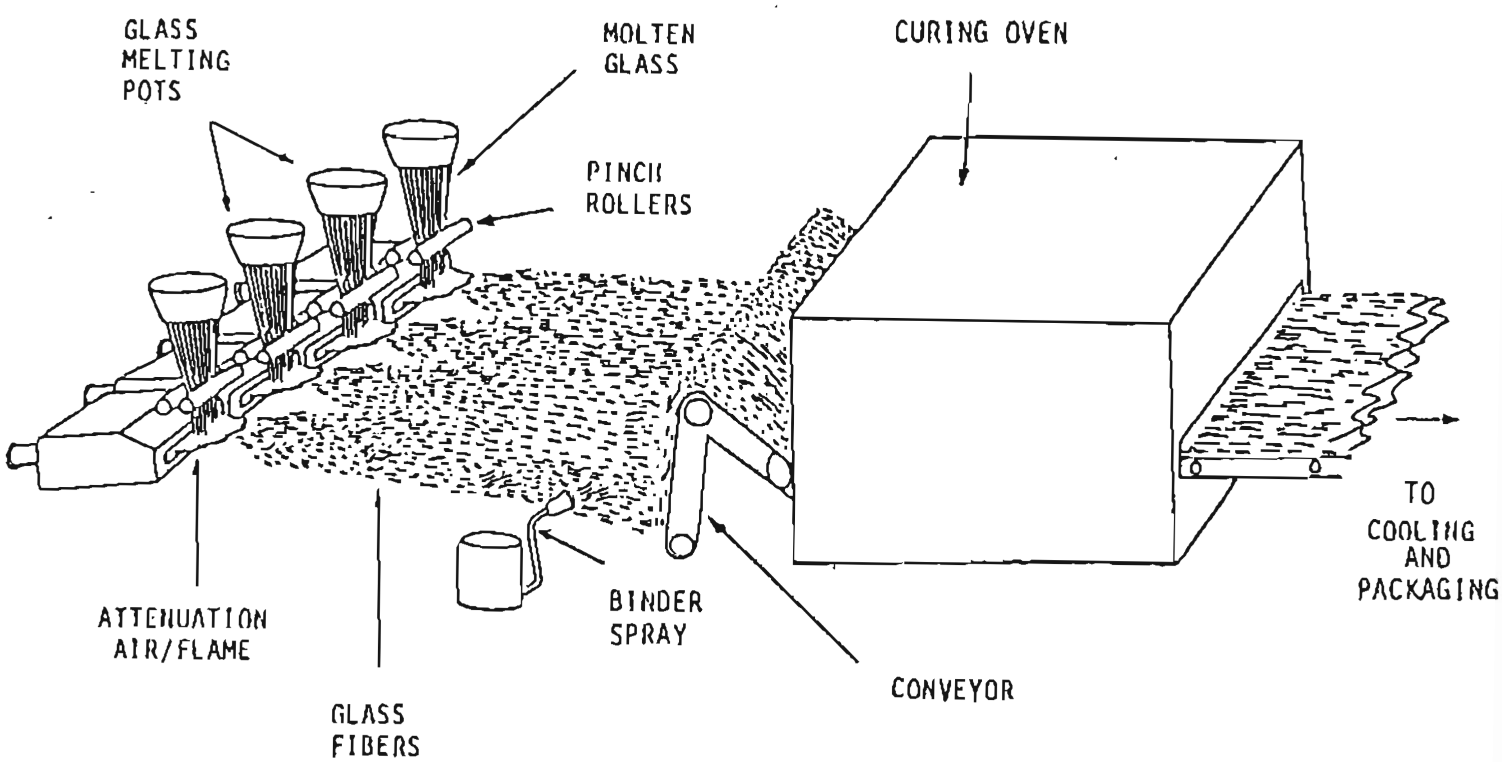

Figure 4. Flame attenuation process. (Source: EPA 1983.)

Binder Application. The fibers formed by the RS or FA processes are generally sprayed with binder, usually a phenol-formaldehyde resin. Binder on RS lines is usually applied through a ring around the bottom of the spinner bucket. Binder is applied to the fibers formed on FA lines at a short distance from the attenuating flames. In some processes, such as the production of Insulsafe® blowing wool which is produced directly from the melt and not as a reclamation product, fibers are collected and processed without the application of binder. Blowing wool production is discussed under cutting/trimming below.

Fiber Collection. After the binder is applied, the fibers are pulled onto a conveyor by suction air, forming a continuous fiberglass mat. This process area is always under negative pressure because of the high volume of suction air used to collect the fibers onto the conveyor. The suction air rate is dependent on the product being made and on company practice, and generally increases linearly with line capacity. The thickness of the uncured fiberglass mat can be varied by varying the glass pull rate and/or the conveyor speed, and the desired thickness of the uncured mat is determined by the desired thickness of the final product being made. The pull rate (typically one to six tons per hour) can be varied by changing the number of spinners or melting pots on the line (EPA 1983, Certain-Teed 1986b, Pundsack 1974).

Curing. The resin impregnated mat formed on the conveyor by either the RS or FA process is conveyed to a curing oven. In the manufacture of pipe insulation the fiberglass mat is removed from the conveyor, cut to desired length, and applied to a pipe mold before curing. In the manufacture of standard insulation products, the mat passes continuously from the forming section through the curing section by conveyor. The curing oven drives off the moisture from the fiberglass mat and sets the binder. A typical oven has from four to seven zones; the zone temperatures vary depending on the resin used and the product being made. The oven is exhausted to the atmosphere; the oven exhaust rate depends on the product being made and on company practice. The curing oven is always operated under negative pressure (Certain-Teed 1986b, NIOSH 1977, EPA 1983).

The thickness of the cured mat is controlled by adjusting compression rollers at the front of the oven. This determines the density of the final product. Uncured mat is sometimes sold for applications such as molding into automobile hoods (Knauf 1986, EPA 1983).

Cooling. The cured mat is conveyed out of the curing oven and is generally cooled with ambient air before further processing. In some plants, the cooling section exhaust is combined with the forming section and/or cooling oven exhaust (EPA 1983).

Backing Application. Adhesive and backing material are generally applied automatically to the fiberglass mat after it is cooled. The cooling of the mat prevents the adhesive from overheating and reduces the fire hazard. Some products are sold without backing (EPA 1983).

Cutting/Trimming and Rolling/Packaging. The insulation product is trimmed so that the edges are uniform and the mat is then cut to the desired lengths. In the past, this trimming and cutting was a manual process, but it is now more automated (Knauf 1986, Certain-Teed 1986b). In general, this is the first point in the fiberglass mat production process where an operator handles the product (Konzen 1974). In the production of many insulation products, the product is produced and packaged without any handling by an operator. The cut and trimmed product is either packaged manually or by an automatic compression bagger, or it undergoes further processing into such products as acoustic ceiling tile. Secondary process steps for manufacture of specialty products are discussed in Section B, Fiber Use.

The trimmings are reclaimed and milled to reduce fiber size. The milled fibers are either blown back into the glass furnace or are sold directly as blowing wool (NIOSH 1977). One Manufacturer (Certain-Teed 1986b) makes a blowing wool product (Insulsafe®) directly from the raw fibers, and not as a by-product of fiberglass mat manufacture. This product is similar to by-product blowing wool except that it contains no binder.

(2) Engineering Controls and Protective Equipment

The forming, curing, and cooling areas are always locally ventilated; however, not all plants use particulate control devices to collect fibers from the ventilation exhaust before release to the atmosphere. These local ventilation systems reduce occupational exposure to fiberglass dust (and resin) by exhausting fiber-laden air from the process area and by keeping these sections of the line under negative pressure (Certain-Teed 1986b). No data are available to quantify the efficiency of these ventilation systems for reducing fibrous dust levels in the plant. Monitoring data, however, indicate that exposure levels in these areas are very low (see Section 3 below).

Engineering controls are also applied to areas where there is a high potential for dust generation such as during cutting, trimming, or packaging. These processes were historically performed manually in many plants, but they have become more highly automated, particularly at plants operated by large manufacturers (Knauf 1986, Certain-Teed 1986b). Dust exposure is usually controlled by vacuum systems; dust may be removed from the vacuum exhaust stream by filters, baghouses, and/or wet collectors, or the dust may be exhausted directly to the atmosphere. Examples of areas where vacuum dust control systems are used include the automatic fiberglass mat cutting area on the conveyor, the automatic bagger chamber, and the scrap recovery areas (Dement et al. 1972a, Dement and Zumwalde 1972, NIOSH 1977, Owens-Corning 1986b).

Particulate control devices are used at several points on the fiberglass wool insulation production lines. Forming air is generally exhausted to a particulate control system, generally a wet scrubber or wet electrostatic precipitator (ESP). The curing ovens may be exhausted to an incinerator, wet ESP, or high efficiency air filter (HEAF). Approximately 35 percent of the forming and curing sections of the RS lines surveyed in 1982 by EPA did not control the atmospheric emissions from their ventilation systems (i.e., fibers were exhausted to the atmosphere instead of being collected). Sixty percent of the cooling sections of the lines surveyed also did not control atmospheric emissions from their ventilation systems (EPA 1983). Dust controls and local ventilation are not generally applied in the spinning or binder application areas, as there is little potential for dust generation since this section of the process is under negative pressure (NIOSH 1977, Knauf 1986).

Local ventilation is also used for the purpose of general plant housekeeping, as well as for industrial hygiene. Vacuum systems are used for general plant housekeeping; mobile riding vacuums are used to clean plant work areas, while local vacuum systems are used to clean around conveyors and other equipment (NIOSH 1977, Certain-Teed 1986b). Compressed air systems, which were considered by NIOSH to be a significant occupational exposure hazard, were widely used historically for cleaning equipment (NIOSH 1977, Dement and Zumwalde 1972). These systems have been largely phased out in favor of vacuum systems (Certain-Teed 1986b).

Protective equipment for workers in fiberglass plants is generally intended to protect against exposure to binder components rather than fibers. Respirators are worn by workers when cleaning out dust filters and curing ovens and in other areas where potential exposure to respiratory hazards is deemed a concern (Knauf 1986, NIOSH 1984, Certain-Teed 1986b).

2. Textile Fiberglass

In general, the production of textile fiber is a continuous process, where continuous strand is produced directly from the glass melt, and then sold or processed further into products. In this process the production of the continuous strand is relatively easily separated from the production of products from the strand.

a. Fiber Producers

Textile fiberglass is manufactured by seven companies at a total of 14 locations in the U.S. Table 2 shows the location of and total employment at each plant (ICF 1986).

b. Production Process/Potential Exposure Points

Textile fiberglass is produced in continuous strands from the glass melt. The molten glass flows through the forehearth and into a series of perforated platinum bushings. Filaments are formed as the glass flows through the bushing orifices. These filaments are collected into a strand, to which binder is applied. The strand is wound onto a drum and dried. The continuous fibers are subjected to additional processing such as twisting and plying (to make fiberglass yarn), weaving (to make fabrics), and chopping (to make chopped strand) in the production of finished products (Pundsack 1974, Konzen 1974, FGI 1986, Owens-Corning 1983).

Bonded mat is used to make coarse air filters, ceiling tiles, fiberglass ducts, roofing material, and other products, and is made using a modified

Table 2. Manufacturers of Textile Fiberglass

Company	Plant Location	Number of Employees at Plant Site
F.G.I. Fibers	Amsterdam, NY	120
Lundy Technical Center	Pompano Beach, FL	180
Manville Corporation	Etowah, TN	150
	Waterville, OH	500
Nicofibers	Shawnee, OH	102
Owens-Corning Fiberglass	Aiken, SC	1,700
	Amarillo, TX	650
	Anderson, SC	1,000
	Huntington, PA	667
	Jackson, TN	900
PPG Industries	Lexington, NC	1,300
	Shelby, NC	1,500
GAF Fibers (formerly Reichold Chemical)	Irwindale, CA	151
	Nashville, TN	235

Sources: Dun's Market Identifier 1986, Textile Economics Bureau 1982-86.

textile process. Continuous fibers are produced from the glass melt through platinum bushings. The continuous fibers are attenuated by air or flame jets and are collected onto a conveyor in a random fashion rather than being wound on a drum. A binder is applied to the textile mat, which is then cured in an oven and wound on tubes. The bonded mat is further processed into finished products (Dement et al. 1972b, Dement and Zumwalde 1972, Roper 1976).

The formation processes for textile fiberglass result in a continuous strand with a very narrow fiber diameter distribution. As the fiber is continuous, and binder is applied immediately upon its formation, there is little potential for dust exposure in the forming area of the process. The measured levels of airborne fiber in textile fiber fabrication areas are also very low (NIOSH 1977, Dement 1973), although somewhat greater than in the forming area. For this reason, NIOSH and industry sponsored exposure studies and EPA regulations have focused on fiberglass wool manufacture (including specialty products such as fiberglass filters, and paper and bonded mat (which is actually a modified textile product)). Also, the majority of exposure data found in the literature has been for fiberglass wool and specialty product manufacture. The remainder of the report will discuss primarily fiberglass wool production, with less emphasis on textile fibers.

3. Extent of Exposure

Nominal fiber diameters for standard insulation products range from 1.5 μm to 15 μm; textile products have similar nominal diameters (although some very large diameter fibers are produced) but generally have much narrower diameter distributions. Specialty fine fiber products such as aircraft insulation are made from fibers which are approximately 1 μm in diameter. Microfiber products such as fiberglass paper and filtration products are manufactured from fibers less than 1 μm in diameter. Blowing wool, including Insulsafe® manufactured by Certain-Teed, is manufactured as loose wool fibers; these fibers are similar in diameter to those used to manufacture standard insulation products.

A large amount of monitoring data is available for fiberglass wool plants. Most manufacturers have been conducting in-house monitoring since the early 1970's. The industry data are supplemented by numerous academic studies (IHF 1982, IHF 1983) and a series of plant health hazard evaluation reports and industrywide studies prepared by NIOSH. Many of these studies contain both personal and area monitoring data for fibrous glass. Although much of the data in the literature dates back to the early to mid-1970s, current dust levels are comparable to older data (Owens-Corning 1986b). Analysis of recent data shows, however, that present exposure levels are in some cases less than those reported in earlier studies, depending on the engineering controls recently installed.

Many of the exposure studies relate exposure levels to job classification (NIOSH 1984, Esmen et al. 1979, Dement and Zumwalde 1972, Dement et al. 1973). These are useful in identifying which workers (if any) are potentially exposed to significant concentrations of fibrous glass. These studies do not, however, provide any information about the number of potentially exposed workers in each job category. It should be noted that the fiberglass industry has become highly automated. Many of the job classifications which appear in earlier NIOSH studies may have different exposure characteristics than in the past because the workers have been removed from the exposure area. As previously discussed, the production of some fiberglass wool products is completely automated and does not involve any operator handling of fiberglass (Cherrie and Dodgson 1985, Certain-Teed 1986b, Knauf 1986).

A discussion of the available NIOSH and literature exposure data for fiberglass wool production facilities is presented below. Exposure levels are related to process locations and/or job classifications where possible. Airborne fiber size distributions are also presented below to indicate the potential respirability of airborne fibers.

a. Exposure Levels

Esmen, et al. (1979) summarized airborne dust and fiber exposure levels at sixteen man-made mineral fiber production facilities. Two of these facilities produced textile fiberglass only, nine produced fiberglass wool and wool products. The level of fabrication of products at the nine fiberglass wool plants varied from light to heavy. The authors found that generally about 80 percent of the employees were directly involved with production, and 20 percent with services.

The study identified the nominal size of the fibers produced at each plant and grouped the exposure data into the following six broad job classifications:

Forming -- All "hot end" or furnace area workers. These include furnace operators, charging operators, batch mixers, and transfer operators.

Production -- "Cold end" or production line workers not involved in product finishing or general manufacturing operations. These include machine operators in direct contact with fiberglass.

Manufacturing -- Workers involved in trimming, sawing, cutting, and finishing operations, or workers handling boxed or packaged material.

Maintenance -- Workers involved in repair of production machinery and general plant housekeeping.

Quality Control -- Product sampling and testing for QA/QC.

Shipping -- Transportation of packaged material.

Table 3 lists the types and nominal diameter of the fibers produced at the production facilities surveyed.

Table 3. Nominal Diameter of Fibers Produced by Fiberglass Plants

Facility	Type(s)	Nominal Fiber Diameter	Level of Fabrication
1	Wool and Textile	1 μm to 12 μm	Moderate
3	Wool	3 μm to 6 μm	None
4	Wool	1 μm to 6 μm	Light
6	Wool and Textile	5 μm to 15 μm	Moderate
8	Wool[a]	7 μm to 10 μm	Heavy
9	Wool	7 μm to 10 μm	Moderate
10	Textile	6 μm to 16 μm	Heavy
12	Wool and Textile	6 μm to 115 μm	Heavy
14	Textile	6 μm to 13 μm	Moderate
15	Wool	0.05 μm to 1.6 μm	Heavy
16	Wool	6 μm to 10 μm	Moderate

[a] Fibers are shipped to this plant from another facility.

Source: Esmen et al. 1979.

Personal samples were taken from within the breathing zone of the workers by having them wear a filter with holder and pump while working. Individuals sampled at each job site were selected at random. Samples were collected on 37 mm diameter type AA membrane filters (0.8 μm pore size). The filters were dessicated before use and placed in completely enclosed plastic filter holders. For sample collection, one part of the filter holder was removed, and the filter was used in open face mode.

Air was drawn through the filters at 2 liters per minute for 7-8 hours. The filters were then sealed in the holders to await analysis. Airborne fiberglass samples were analyzed using optical microscopy (OM) and electron microscopy (EM) analyses. OM analysis measures the concentration of fibers greater than or equal to 1 μm in diameter, while EM analysis measures the concentration of fibers less than 1 μm in diameter.

For optical microscopy, a section of the filter was rendered transparent by chemical treatment. The membranes were then analyzed using phase contrast illumination. The total magnification of the microscope was 400X, and the resolution was to 0.56 μm diameter, although particles of 0.3 μm diameter could be distinguished. The number of fibers was determined by sampling 40 or more microscopic fields for each filter. The minimum detectable fiber count was 0.0012 fibers/cc.

For electron microscopy, the filters were ashed and a suspension was made by chemical treatment of the ash. The suspension was spread into a film on an electron microscope grid and evaporated. The grids were examined using an electron microscope with a magnification of 2000X. The resolution of the microscope was about 50 to 100 angstrom units, and the minimum detectable fiber count was 0.0023 fibers/cc (based on an 8-hour sample).

Tables 4 and 5 summarize the fiber concentrations determined by OM and by EM for the eleven fiberglass facilities surveyed, respectively. With the exception of the production area of facility 1, which the authors report was operated by inexperienced personnel, mean fiber levels measured by optical microscopy were well below 0.1 fibers/cc in all areas of all facilities except Facility 15. Facility 15 produces fibers with a nominal diameter between 0.5 µm and 1.6 µm, often referred to as microfibers (see Table 3). EM analysis indicates that the average concentration of fibers 1 µm or less in diameter exceeds 2 fibers/cc in the forming, production, manufacturing, and quality control areas of this plant.

The authors did not identify the types of products manufactured at the plants surveyed. In general, average fiber exposure levels were lowest in the forming area and highest in the production and manufacturing areas of the surveyed plants. Average exposure levels for the textile fiber facilities appear to be comparable to levels for fiberglass wool facilities manufacturing similar diameter fibers, as illustrated in Tables 4 and 5.

There is a large variation in the exposure to submicron fibers within the same job classification from plant to plant. Figure 5 illustrates the relationship between the average fiber exposure and the nominal fiber diameter for each plant. The variation of exposure levels between plants within the same job classification is not significant after the differences in nominal fiber diameter are accounted for.

Exposure data for fiberglass production plants were summarized in several papers presented at a 1974 symposium sponsored by NIOSH. Corn (1974) categorized data collected at three plants by job classification, product type, and fiber length and diameter. Both personal and environmental (area) samples were taken.

Table 4. Summary of Fiber Concentration in Fiberglass Production Facilities as Determined by Optical Microscopy (Fibers >1 um in Diameter)

	Plant Operations													
	Forming		Production		Manufacturing		Maintenance		Quality Control		Shipping		Overall	
Facility[a]	C[b]	σ[c]	C	σ	C	σ	C	σ	C	σ	C	σ	C	σ
1	0.0025	0.0008	0.38	0.32	0.031	0.015	0.022	0.021	0.074	0.099	0.011	0.0011	0.0094	0.25
3	-[d]	-	0.022	0.021	-	-	0.068	0.18	-	-	0.0053	0.0079	0.035	0.10
4	0.0061	0.0039	0.072	0.12	0.038	0.049	0.025	0.021	0.012	0.0082	0.018	0.011	0.042	0.077
6	0.045	0.10	0.007	0.0057	0.0088	0.0091	0.012	0.031	0.011	0.019	0.0047	0.0035	0.012	0.032
8	-[e]	-	0.025	0.02	0.035	0.031	0.011	0.009	-	-	0.008	0.007	0.021	0.022
9	0.024	0.018	0.014	0.007	0.019	0.066	0.013	0.0064	-	-	0.004	0.0023	0.017	0.014
10	0.0012	0.0014	0.0031	0.0038	0.0037	0.0035	0.0023	0.0028	0.0026	0.0030	0.0018	0.0018	0.0024	0.0032
12	0.013	0.0093	0.016	0.031	0.0077	0.0039	0.011	0.015	0.01	0.0028	0.0067	0.0052	0.012	0.017
14	0.013	0.013	0.043	0.093	0.046	0.054	0.054	0.13	-	-	0.033	0.027	0.037	0.031
15[f]	0.19	0.22	0.92	1.02	1.56	3.79	0.11	0.10	0.89	0.33	0.097	0.092	0.78	2.1
16	0.022	0.0074	0.024	0.022	0.049	0.033	0.066	0.23	0.035	-	0.015	0.0088	0.04	0.12

[a] Plants 2, 5,7, 11 and 13 are mineral wool production facilities.

[b] Arithmetic Mean -- fibers/cc.

[c] Standard Deviation -- fibers/cc.

[d] - Indicates the lack of data for the entry.

[e] Plant 8 receives fibers from another facility and there are no forming operations at the plant.

[f] Facility 15 produces fine diameter, 0.5 um-1.6 um, fiberglass.

Source: Esmen et al. 1979.

Table 5. Summary of Fiber Concentration in Fiberglass Production Facilities as Determined by Electron Microscopy (Fibers <1 um in Diameter)[a]

	Plant Operations													
	Forming		Production		Manufacturing		Maintenance		Quality Control		Shipping		Overall	
Facility	C[b]	σ[c]	C	σ	C	σ	C	σ	C	σ	C	σ	C	σ
1	0.0022	0.0001	0.73	2.3	0.012	0.007	0.013	0.028	0.45	0.76	0.0023	0.0023	0.38	0.17
3	-[d]	-	0.0031	0.032	-	-	0.20	0.71	-	-	0.0047	0.0034	0.083	0.42
4	0.0081	0.0045	0.19	0.29	0.12	0.42	0.017	0.016	0.023	0.014	0.0092	0.0052	0.10	0.28
6	0.0023	0.0008	0.0044	0.0042	0.0039	0.0030	0.0084	0.028	0.0067	0.0094	0.0036	0.0038	0.0052	0.015
8[e]	-	-	0.052	0.041	0.016	0.012	0.02	0.016	-	-	0.015	0.011	0.025	0.031
10	0.0031	0.0017	0.0026	0.0019	0.0035	0.0020	0.0081	0.012	0.0024	0.0023	0.0024	0.0023	0.0043	0.0067
12	0.0056	0.0054	0.0037	0.0047	0.0028	0.0033	0.0024	0.0005	0.0053	0.0037	0.0025	0.0006	0.0034	0.0038
15[f]	2.0	2.6	6.49	9.37	5.25	14.6	1.3	2.2	12.0	5.83	0.58	0.38	4.4	9.9
16	0.029	0.021	0.042	0.025	0.071	0.040	0.22	0.84	0.025	-	0.0083	0.0067	0.089	0.043

[a] Electron microscopic data for facilities 9 and 14 are not reported because the analysis method used for these facilities was not as reliable as the method used for the reported data.

[b] Arithmetic Mean -- fibers/cc.

[c] Standard Deviation -- fibers/cc.

[d] - Indicates the lack of data for the entry.

[e] There are no forming operations at Plant 8.

[f] Facility 15 produces fine diameter, 0.5 um-1.6 um, fiberglass.

Source: Esmen et al. 1979.

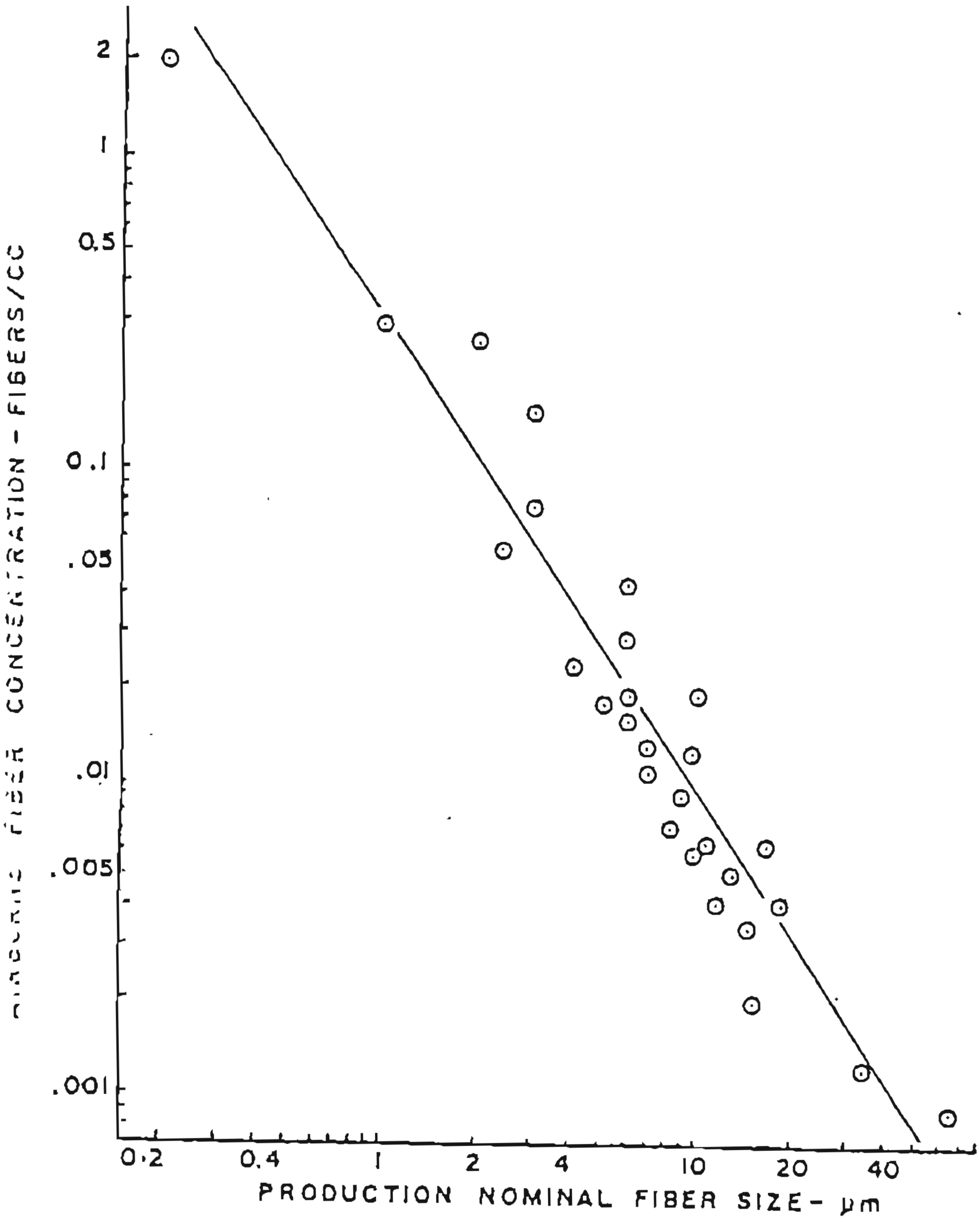

Figure 5. Relationship between measured average exposures (determined by phase contrast microscopy) and nominal diameter of fiber manufactured. (Source: Esmen et al. 1979.)

Personal samples were taken from within the breathing zone of employees working in areas of potential exposure. This was done by having workers wear a filter with holder and pump while performing their work duties. Environmental samples were obtained from large plant areas that employees traversed while performing their duties. Environmental filters were placed at breathing level. To prevent overloading the filters, the filters were replaced with fresh filters every two hours. Personal samples are thus not 8-hour average exposures, but 2-hour averages. Operations sampled were selected such that the 2-hour averages would be higher than 8-hour averages.

Samples were collected on 37 mm diameter Type AA membrane filters (0.8 μm pore size). These were dessicated before use and placed in completely enclosed plastic filter holders. One part of the filter holder was removed prior to sampling, and the filter was used in an open-face mode, oriented face down during sampling. Air was drawn through the filters at 2 liters per minute for two hours.

The filters were analyzed using both optical (OM) and electron (EM) microscopy techniques. For optical microscopy, a section of the filter was rendered transparent by chemical treatment. The membranes were then analyzed using phase contrast illumination. The total magnification of the microscope was 400X, and the resolution was to 0.56 μm diameter. Particles of 0.2 μm diameter could be distinguished. The number of fibers was determined by sampling 40 or more microscopic fields for each filter. The minimum detectable fiber count was 0.01 fibers/cc. For electron microscopy, the filters were ashed and a suspension was made by chemical treatment of the ash. The suspension was spread into a film on an electron microscope grid and evaporated. The grids were examined using an electron microscope with a magnification of 2000X. The resolution of the microscope was about 50 to 100 angstrom units, and the minimum detectable fiber count was 0.6 fibers/cc.

Plant A produced a variety of fiberglass wool products, and Plant B produced a mixture of textile fiber and fiberglass wool products including microfiber products. Plant C produced exclusively molded products, so results for Plant C are not discussed.

A partial summary of the optical microscopy data for Plants A and B is included in Tables 6 and 7, respectively. The samples generally contained less than 60 percent respirable fibers (less than 3.5 µm in diameter). No fibers less than 1 µm were reported at most of the locations sampled. The EM data are not included in Tables 6 and 7.

With the exception of one personal sample taken in Plant A (one of four personal samples on the selector packer at the wool production plant) and three samples taken in Plant B (two personal samples on the Helix operator in the textile fiber production area and one of two personal samples on the machine operator in the microfiber area) all dust concentrations were less than 0.22 fibers/cc. The two Helix operator concentrations are greater than 0.5 fibers/cc and are very high compared to the rest of the data. No explanation of these high concentrations are provided in the report (Corn 1974).

There was a large variation in measured concentrations between duplicate samples in this study. However, it appears that exposures levels are lower in the fiber production area (hot end) than in the fiber processing area (cold end) in both wool and textile plants. This is to be expected based on the nature of the formation and fabrication processes. Fabrication of the fiber products generally involves workers being in closer proximity to the fiberglass and/or processes (e.g., sawing/cutting for wool products and

Table 6. Results of Sampling for Total Suspended Particulate Matter and Airborne Fibers in Plant A

Manufacturing Operations, Type of Sample, and Description of Sampling Site	TSPM[a] Concentration (mg/m^3)	Fiber Concentrations (fibers/cc) Determined by Phase Contrast Microscopy: Length <5 um	Length >5 um	Percent <3.5 um In Diameter, Length >5 um	Length >10 um	Comments
Recondition Department						
Personal: Feeder End	3.3	0.02±0.02	0.04±0.03	50	50	
Personal: Group Leader	4.3	0.02±0.01	0.07±0.03	45	44	Sample obtained on group leader, who travels throughout department
Environmental: Packing End	5.2	0.03±0.02	0.10±0.04	75	63	Among three packers
Environmental: Packing End	1.2	0.07±0.03	0.05±0.02	21	21	Sample taken at location as above
Molded Pipe Plant						
Personal: Cold End Saws and Packaging Operations	3.7	0.05±0.03	0.07±0.03	33	11	Sample obtained on group leader, who travels throughout the department
Personal: Saw Operations	3.8	0.02±0.02	0.09±0.03	60	40	
Personal: Cold End Saws and Packaging Operations	2.6	0.05±0.02	0.09±0.03	43	29	Group leader
Personal: Press Operation	4.4	0.09±0.04	0.04±0.02	29	0	
Warehouse						
Environmental	2.0	0.03±0.01	0.05±0.02	55	18	Light traffic
Environmental	1.0	0.02±0.01	0.02±0.01	50	17	Very light traffic
Flame Drawn Fiber Plant						
Environmental: Furnace Platform	1.8	0.04±0.02	0.05±0.02	55	18	
Environmental: Furnace Platform	0.07	0.02±0.01	0.02±0.01	60	0	

Table 6 (Continued)

Manufacturing Operations, Type of Sample, and Description of Sampling Site	TSPM[a] Concentration (mg/m^3)	Fiber Concentrations (fibers/cc) Determined by Phase Contrast Microscopy: Length <5 um	Length >5 um	Percent <3.5 um in Diameter: Length >5 um	Length >10 um	Comments
Flame Drawn Fiber Plant						
Personal: Roll-up Man	4.1	0.07±0.04	0.11±0.04	20	20	
Personal: Roll-up Man	5.5	0.06±0.03	0.03±0.02	33	0	
Personal: Roll-up Man	2.3	0.05±0.02	0.02±0.02	33	33	
Personal: Roll-up Man	2.1	0.08±0.03	0.07±0.03	47	20	
Bonded Mat Plant						
Environmental: Hot End at Operator's Station	0.7	0.04±0.02	0.05±0.02	57	0	
Environmental: Hot End at Operator's Station	0.7	0.01±0.01	0.02±0.02	67	33	
Personal: Roll-up Man	1.8	0.07±0.03	0.10±0.04	58	8	
Personal: Roll-up Man	2.3	ND[b]	0.06±0.03	75	0	Repeat of above sample
Textile Mat Section						
Environmental: Forming End Between Two Lines	1.5	0.05±0.02	0.06±0.03	36	0	
Environmental: Forming End Between Two Lines	1.4	0.19±0.05	0.11±0.04	23	5	Repeat of above sample
Environmental: At Roll-Up Station	3.0	0.05±0.03	0.10±0.04	45	22	
Environmental: At Roll-Up Station	3.3	0.05±0.03	0.06±0.03	14	0	

Table 6 (Continued)

Manufacturing Operations, Type of Sample, and Description of Sampling Site	TSPM[a] Concentration (mg/m^3)	Fiber Concentrations (fibers/cc) Determined by Phase Contrast Microscopy: Length <5 um	Length >5 um	Percent <3.5 um in Diameter: Length >5 um	Length >10 um	Comments
Wool Plant						
Environmental: Fore-hearth	2.7	0.10±0.03	0.03±0.02	18	12	
Environmental: Fore-hearth	2.6	0.09±0.03	0.05±0.02	35	18	Sample taken at same location as above
Environmental: Paper Pit, Furnace End	2.8	0.04±0.02	0.03±0.02	38	25	
Environmental: Paper Pit, Furnace End	0.9	0.01±0.01	ND	0	0	Sample taken at same location as above
Personal: Selector-Packer	3.4	0.03±0.02	0.04±0.03	40	0	Making full-wall unfaced thermal insulation
Personal: Selector-Packer	4.9	0.09±0.04	0.14±0.05	63	8	Assistant group leader
Personal: Selector-Packer	2.3	0.05±0.02	0.08±0.03	25	19	Making appliance wool
Personal: Selector-Packer	1.8	0.02±0.01	0.01±0.03	58	33	

[a] TSPM = Total Suspended Particulate Matter.

[b] ND = None Detected.

Source: Corn 1974.

Table 7. Results of Sampling for Total Suspended Particulate Matter and Airborne Fibers in Plant B

Manufacturing Operations, Type of Sample, and Description of Sampling Site	TSPM[a] Concentration (mg/m^3)	Fiber Concentrations (fibers/cc) Determined by Phase Contrast Microscopy: Length <5 um	Length >5 um	Percent <3.5 um in Diameter: Length >5 um	Length >10 um	Comments
Fiber Production Area						
Personal: Glass Furnace-Fiber Wind Up	2.1	0.02±0.01	0.01±0.01	33	0	
Personal: Glass Furnace-Fiber Wind Up	1.1	0.05±0.02	0.04±0.02	46	8	Same man as sampled above
Personal: Fiber Forming Winding Level	5.2	0.02±0.01	0.01±0.01	33	0	
Personal: Fiber Forming Winding Level	4.7	0.03±0.02	0.02±0.01	33	17	Same man as sampled above
Personal: Fiber Forming Crucible Level	1.1	0.03±0.02	0.04±0.02	43	14	
Personal: Fiber Forming Crucible Level	1.4	0.01±0.01	ND[b]	0	0	Same man as sampled above
Cold Fiber Handling Operations						
Environmental: Textiles	0.1	0.02±0.01	0.01±0.01	20	20	
Environmental: Rovings by Creel Storage Between Two Rovings Assignments	0.8	0.8±0.02[c]	0.12±0.03	58	25	
Environmental: Weaving Room	0.1	0.05±0.02	0.03±0.01	50	50	
Environmental: Chopped Strand	3.5	0.05±0.03	ND	0	0	
Environmental: Chopped Strand	0.8	0.02±0.01	0.05±0.02	50	25	Repeat of above sample

Table 7 (Continued)

Manufacturing Operations, Type of Sample, and Description of Sampling Site	TSPM[a] Concentration (mg/m^3)	Fiber Concentrations (fibers/cc) Determined by Phase Contrast Microscopy: Length <5 um	Length >5 um	Percent <3.5 um in Diameter: Length >5 um	Length >10 um	Comments
Hot Fiber Handling Operations						
Personal: Chopped Mat-Quality Control Man	1.4	0.05±0.03	0.07±0.03	56	33	
Personal: Chopped Mat-Quality Control Man	0.5	0.04±0.02	0.08±0.03	63	25	Same man as sampled above
Environmental: Ply Mat Left Front of Input End	0.7	0.03±0.01	0.02±0.01	37	13	
Personal: Bonded Mat-Cold End: Take-up Rolls	1.1	0.12±0.05	0.10±0.05	45	33	
Environmental: Bonded Mat-Cold End: Band Saw	0.6	0.03±0.01	0.02±0.01	50	19	
Environmental: Bonded Mat-Hot End	0.7	0.02±0.01	0.02±0.01	50	30	Sample taken near bushings
Personal: Helix Operator	3.6	0.07±0.03	0.49±0.08	47	33	
Personal: Helix Operator	1.3	0.15±0.05	0.81±0.11	35	16	Same man as sampled above
Microfibers Area						
Environmental: Hot End	0.1	0.03±0.01	0.01±0.01	11	0	Sample taken near bushings
Personal: Cold End, Machine Attendant	0.6	0.09±0.03	0.17±0.04	62	50	
Personal: Cold End, Machine Attendant	0.8	0.04±0.02	0.09±0.03	67	58	Same man as sampled above
Personal: Cold End, Machine Attendant	0.4	0.04±0.02	0.08±0.03	44	22	

Table 7 (Continued)

Manufacturing Operations, Type of Sample, and Description of Sampling Site	TSPM[a] Concentration (mg/m^3)	Fiber Concentrations (fibers/cc) Determined by Phase Contrast Microscopy: Length <5 um	Length >5 um	Percent <3.5 um in Diameter, Length >5 um	Percent <3.5 um in Diameter, Length >10 um	Comments
Chopped Mat						
Environmental: Creel Area	0.2	0.01±0.01	0.01±0.01	25	0	
Environmental: Take-up	0.02	0.02±0.01	ND	0	0	

[a] TSPM -- Total Suspended Particulate Matter.

[b] ND -- None Detected.

[c] This data point may be a misprint. In the original report, it is much higher than any of the other data points and may actually be 0.08 rather than 0.8.

Source: Corn 1974.

chopping for textile products) which can generate airborne fibers. Formation of the wool fiber generally occurs under negative pressure, and textile fibers are formed as a continuous strand. Both of these processes have a low potential for fiber generation.

Another paper presented at the 1974 NIOSH Symposium (Dement 1974) compared exposure levels at facilities producing large diameter and microfiber (≤1.0 µm diameter) insulation and specialty products (see Tables 8 and 9). Samples for fiber count and fiber size were collected on 37 mm diameter membrane filters. Air was drawn through the filters at 2 liters per minute for 4 to 6 hours. Large diameter (greater than 1 µm) fibers were counted and sized by optical phase contrast microscopy using 430X magnification. Samples expected to contain fibers less than 1 µm in diameter were counted using an oil immersion technique at 1000X magnification. Samples containing small diameter fibers were examined by electron microscopy (16000X magnification) to determine size distribution. At least 50 microscopic fields were counted for large diameter fiber samples, and over 100 fields for samples containing small diameter fibers. All optical microscopy samples were mounted for analysis using the asbestos method current at the time the samples were analyzed (1972-73).

Fiber concentrations at the large diameter fiber operations were generally less than 0.1 fibers/cc, while mean concentrations at microfiber operations ranged from 1.0 to 21.9 fibers/cc. Bulk fiber handling operations at four of six microfiber facilities surveyed (four of which were fabrication facilities) showed concentrations greater than 5 fibers/cc.

Several health hazard evaluation (HHE) reports prepared by NIOSH present exposure data for fiberglass production facilities. Many of the available HHE reports date from the early 1970's (Dement et al. 1972a, Dement and Zumwalde

Table 8. Summary of Fiber Concentrations in Large Diameter Glass Fiber Insulation Production Facilities

Operation	Plant A	Plant B	Plant C	Plant D
CENTRIFUGAL FORMED BUILDING INSULATION				
Mean (fiber/cc)	0.07	0.08	0.09	0.09
Range (fiber/cc)	(0.04-0.13)	(0.00-0.18)	(0.08-0.12)	(0.01-0.83)
Number of Samples	9	19	4	22
CENTRIFUGAL FORMED APPLIANCE INSULATION				
Mean (fiber/cc)	-	0.04	-	0.06
Range (fiber/cc)	-	(0.01-0.11)	-	(0.02-0.09)
Number of Samples	-	13	-	22
FLAME ATTENUATED INSULATION				
Mean (fiber/cc)	0.04	-	0.14	-
Range (fiber/cc)	(0.02-0.06)	-	(0.04-0.24)	-
Number of Samples	8	-	2	-
PIPE INSULATION				
Mean (fiber/cc)	0.07	-	0.14	-
Range (fiber/cc)	(0.03-0.12)	-	(0.06-0.27)	-
Number of Samples	10	-	6	-
SCRAP RECLAMATION				
Mean (fiber/cc)	0.06	0.07	0.10	0.07
Range (fiber/cc)	(0.03-0.15)	(0.02-0.47)	(0.08-0.13)	(0.01-0.14)
Number of Samples	10	4	5	7
ALL OTHER OPERATIONS				
Mean (fiber/cc)	0.07	0.04	0.20	-
Range (fiber/cc)	(0.01-0.13)	(0.01-0.08)	(0.04-0.26)	-
Number of Samples	10	12	4	-
ALL OPERATIONS				
Mean (fiber/cc)	0.06	0.11	0.13	0.08
Range (fiber/cc)	0.01-0.13	0.00-0.47	0.04-0.26	0.01-0.83
Number of Samples	47	48	21	49

Source: Dement 1975.

Table 9. Airborne Fiber Concentrations in Operations Producing Small Diameter Glass Fibers

OPERATIONS	Bulk Fiber Production	
	C[a]	E
Bulk Fiber Handling		
Mean (fiber/cc)	1.0	9.7
Range (fiber/cc)	0.1-1.7	0.9-33.6
Number of Samples	5	54
Fabrication and Finishing		
Mean (fiber/cc)	-[b]	5.3
Range (fiber/cc)	-	0.3-14.3
Number of Samples	-	24

[a] In addition to the large wool insulation operations, Plant C had several lines producing small diameter fibers.

[b] Not reported.

Source: Dement 1975.

1972, Dement et al. 1973), others are more recent reports (NIOSH 1984). These reports categorize exposure data by job classification and/or plant area. The purpose of HHE is to identify potential exposure hazards. In most cases, no exposure hazards from glass fibers were identified. In some cases, other exposure hazards (e.g., from formaldehyde, phenol, sytrene, or free silica) were identified at the plants.

A study, primarily concerned with formaldehyde exposure, conducted at Manville's Corona, California fiberglass wool products plant (NIOSH 1984) presented total dust, respirable dust, and fiber concentration data. Samples were collected on 37 mm membrane filters and analyzed by phase contrast microscopy. Counting was performed following NIOSH Method P & CAM 239. Table 10 presents the fiber concentration data. The average fiber diameter produced by this plant is 17 µm; the smallest diameter fibers produced are 3 µm to 5 µm in diameter. The plant does not produce glass from raw materials, but remelts glass marbles shipped to the plant from another facility.

The highest fiber concentrations measured at Manville's plant were at the baler machine (0.17-0.31 fibers/cc), which bales fiberglass wool to facilitate transport and further processing. Exposure levels were much lower in the cutting and wrapping area (0.02-1.10 fibers/cc). All samples were an order of magnitude lower than the OSHA guideline of 3 fibers/cc. Environmental total and respirable dust data taken at the cutting and wrapping area of Manville's plant are presented in Table 11. Total respirable dust was approximately 10 to 15 percent of the total dust measured at this location. Personal total and respirable dust data taken on maintenance workers cleaning the high efficiency air (HEAF) unit are presented in Table 12. Respirable dust accounted for less

Table 10. Personal and Area Air Samples Collected for Fibrous Glass at Manville Corporation's Corona, California Plant

Location	Type Sample	Time Period	Concentration (fibers/cc)[a]
Baler-Machine Attendant	P[b]	0815-1240	0.25
Baler-Machine Attendant	P	1240-1445	0.17
Line 63 -- Cutting and Wrapping	A[c]	0820-1230	0.10
Line 63 -- Cutting and Wrapping	A	1230-1445	0.06
Baler-Machine Attendant	P	0900-1100	0.31
Baler-Machine Attendant	P	1100-1310	0.20
Line 63 -- Cutting and Wrapping	A	0730-1400	0.02

[a] Fibers/cc -- Fibers of fibrous glass per cubic centimeter of air.

[b] P -- Personnel air sample.

[c] A -- Area air sample.

Source: NIOSH 1984.

Table 11. Environmental (Area) Air Samples Collected for Fibrous Glass Dust at Manville Corporation's Corona, California Plant

Location	Type Sample	Time Period	Concentration (mg/m^3)[a]
Line 63 -- Cutting and Wrapping	R[b]	0820-1445	0.04
Line 63 -- Cutting and Wrapping	T[c]	0820-1445	0.40
Line 63 -- Cutting and Wrapping	R	0720-1400	0.20
Line 63 -- Cutting and Wrapping	T	0720-1400	1.45

[a] mg/m^3 -- milligrams of fibrous glass dust per cubic meter of air.

[b] R -- Respirable dust air sample.

[c] T -- Total dust air sample.

Source: NIOSH 1984.

Table 12. Personal Air Samples Collected for Fibrous Glass Dust During HEAF Unit Clean-Out at Manville Corporation's Corona, California Plant

Location	Type Sample	Time Period	Concentration (mg/m^3)[a]
Line 60 -- Machine Attendant, Sunction Box Clean Out Bottom	R[b]	0745-1245	0.18
Line 60 -- Machine Attendant, Sunction Box Clean Out Bottom	T[c]	0745-1200	9.84
Line 60 -- Machine Attendant, Sunction Box Clean Out Top	R	0745-1305	0.11
Line 60 -- Machine Attendant, Sunction Box Clean Out Top	T	0745-1305	2.54

[a] mg/m^3 -- milligrams of fibrous glass dust per cubic meter of air.

[b] R -- Respirable Dust air sample.

[c] T -- Total Dust air sample.

Source: NIOSH 1984.

than 5 percent of the total dust in all samples taken. The report noted that the workers wear respirators when cleaning the HEAF unit.

An older study performed at Owens-Corning's Kansas City, Kansas facility (Dement et al. 1973) presents concentrations of fibers less than 10 μm in diameter for standard (centrifugal forming) and aerocor (airblower forming) insulation production, blowing wool production, and bonded mat production (see Table 13). Samples for fiber count were collected on 37 mm diameter Type AA membrane filters (0.8 μm pore size) at a collection rate of 2.0 liters per minute with an open filter face. Sampling periods ranged from 4 to 5 hours. Fibers less than 10 μm in diameter were counted at 430X magnification by the phase contrast method recommended by NIOSH for counting asbestos fibers. Fiber diameter distributions were determined for most operations using a "Leitz" rotating stage phase contrast microscope at 400X magnification and a calibrated "Porton" reticle. At least 100 randomly selected fibers were sized for each operation.

The highest concentrations (between 0.10 and 0.20 fibers/cc) were recorded in the packer-handler and compactor press areas of the standard insulation line, and in the paper backing removal area in blowing wool production. All other areas sampled showed concentrations less than 0.10 fibers/cc, and most areas showed less than 0.05 fibers/cc. In all areas, the median airborne fiber diameter was close to 1.1 μm, and approximately 90 percent of the fibers where less than 3.5 μm in diameter which are respirable.

Another study of PPG Industries' Shelbyville, Indiana fiberglass wool production plant (Dement et al. 1972a), reported measurements of fiberglass concentrations in the production of standard and "super fine" insulation

Table 13. Personal and Environmental Samples Collected for Fibrous Glass at Owens-Corning's Kansas City, Kansas Plant

Millipore Sample Number	Job or Sample Location	Fiber Concentration Fibers ≤10 μm in Diameter per cm³
Lines 71 and 72, Aerocor		
12	Packer-Handler, 71 line	0.005
13	Packer-Handler, 71 line	0.034
15	Packer-Handler, 72 line	0.015
17	Forehearth Operator	0.042
36	At Band Saw, 72 line	0.012
52	At Band Saw, 72 line	0.039
37	By Cutter, 71 line	0.110
50	By Cutter, 71 line	0.038
38	By Edge Slitter, 71 line	0.052
51	By Edge Slitter, 71 line	0.052
35	By Chopper, 72 line	0.012
53	By Chopper, 72 line	0.039
99	Edge Trimmer, 71 line	0.058
Aerocor Fabrication		
33	At Chopper, Range Insulation	0.047
34	At Chopper, Range Insulation	0.031
44	On Chopper Platform, Low Density	0.049
46	On Chopper Platform, Low Density	0.069
47	By Punch Press, Range Insulation	0.051
31	At Special Cutting Operation	0.083
32	At Special Cutting Operation	0.031
45	At Special Cutting Operation	0.031
Standard Insulation Wool (Centrifugal Forming)		
1	Packer-Handler, 70 line	0.183
4	Packer-Handler, 70 line	0.127
5	Packer-Handler, 70 line	0.100
6	Packer-Handler, 70 line	0.158
7	Packer-Handler, 70 line	0.096
9	Forming Group Leader	0.038
11	Forehearth Operator, 70 line	0.050
8	Machine Operator, 70 Line	0.051
10	Machine Operator, 70 line	0.074
98	At Compactor Press, 70 line	0.182

Table 13 (Continued)

Millipore Sample Number	Job or Sample Location	Fiber Concentration Fibers ≤10 μm in Diameter per cm^3
Standard Insulation Wool (Centrifugal Forming) (Continued)		
18	Packer-Handler, J-line	0.096
19	Packer-Handler, J-line	0.062
20	Packer-Handler, J-line	0.023
21	Packer-Handler, J-line	0.053
22	Machine Operator, J-line	0.036
23	Forehearth Operator, J-line	0.037
24	Forehearth Operator, J-line	0.006
26	Packer-Handler, K-line	0.046
27	Packer-Handler, K-line	0.093
Blowing Wool		
28	Blowing Wool Packer	0.055
29	Scrap Feeder	0.076
41	Paper Backing Remover	0.147
42	At Scrap Feed Station	0.016
RM-1 Bonded Mat		
40	At Edge Slitter	0.020
49	At Edge Slitter	0.006
39	At Packing Roller	0.034
48	At Packing Roller	0.031

Source: Dement et al. 1973.

products (RS and FA processes, respectively) (see Table 14). Sampling and analysis techniques were similar to those described by Dement et al. (1973) above.

The highest fiber concentrations (0.1 to 0.15 fibers/cc) occur in the scrap reclamation grinder area and in the selector-packer area on the RS line. All other measured concentrations were below 0.1 fiber/cc. There is no significant difference between airborne fiber exposure during production of standard and "super fine" insulation products; both fibers are ≥1 μm in nominal diameter. The median size of the airborne fibers was approximately 2.5 μm for the RS, FA, and molded pipe process lines. Data indicate that 70 to 80 percent of the fibers were respirable.

Konzen (1976) summarized fiber exposure data from 15 Owens-Corning facilities, six of which produced wool insulation products and five of which produced continuous textile fiber (see Table 15); the remaining four were secondary product facilities. Data were categorized by fiber type (wool or textile) and by process or product. Average fiber concentrations in the forming, packing, fabrication, reconditioning, and bonded mat areas of the wool facilities ranged from 0.11-0.16 fibers/cc and approximately 70-90 percent of the airborne fibers were less than 3.5 μm in diameter (i.e., of a respirable size). Data for textile fiber formation (0.13 fibers/cc) show that fiber concentrations in textile forming operations are about equal to those in wool forming operations, but a higher pecentage of the airborne fibers generated from textile forming are respirable (~100 percent based on only 2 samples). Textile fabrication operations generated the highest average airborne fiber exposures, 0.37 fibers/cc. The staple forming and fabrication areas generated the lowest average airborne fiber exposures, 0.07-0.11 fibers/cc.

Table 14. Personal and Environmental Samples Collected for Fibrous Glass at PPG Industries' Shelbyville, Indiana Plant

Operation and Job	Fibers ≤10 μm in Diameter Per cm^3	Total Dust Concentration (mg/m^3)
	SUPER FINE (FA PROCESS)	
Furnace Tender	0.0204	0.39
Furnace Tender	0.0237	1.41
Furnace Tender	0.0416	0.21
Furnace Tender	0.0308	0.25
Lead Operator	0.0573	0.39
Selector Packer	0.0424	0.68
Selector Packer	-[1]	0.59
Selector Packer	0.0627	0.83
Selector Packer	0.0423	0.61
	ROTARY (RS PROCESS)	
Furnace Tender	0.0647	0.33
Selector Packer	0.0768	0.64
Selector Packer	0.0537	1.29
Selector Packer	0.0589	0.21
Selector Packer	0.1349	0.83
Selector Packer	0.1069	0.71
Facing Operator	0.0459	0.74
Box Maker	0.0381	0.50
Box Packer	0.0554	2.36
	MOLDED PIPE	
Forming Machine Operator	0.0505	0.43
Forming Machine Operator	0.0499	0.56
Forming Machine Operator	0.0700	0.41
Mandrel Puller	0.0513	0.09
Mandrel Puller	0.0336	0.30
Oven Attendant	0.0965	0.57
Oven Attendant	-[a]	0.57
Oven Attendant	0.0694	0.40
Mandrel Cleaner	0.0690	Void

Table 14 (Continued)

Operation and Job	Fibers ≤10 μm in Diameter Per cm^3	Total Dust Concentration (mg/m^3)
MOLDED PIPE FACING		
Pipe Facer	0.0565	0.35
Pipe Facer	0.0438	0.27
Pipe Facer	0.0694	0.25
Pipe Packer	0.0125	0.30
SCRAP RECLAMATION		
Scrap Grinder	0.1497	2.49
Scrap Grinder	0.0656	2.14

[a] Count sample void.

Source: Dement et al. 1972a.

Table 15. Airborne Fiber Concentration Data from Owens-Corning Facilities

	Total Dust Concentration (mg/m^3)	Fiber Concentration (number fibers/cc)	Percent Fiber/Total Particulate	Percent Fiber ≤3.5 μm in Diameter
	SELECTED AREAS OF SIX WOOL PLANTS			
Wool Forming	1.66 (59)[a]	0.15 (63)	0.34 (67)	87.1 (52)
Wool Packing and Fabrication	2.02 (259)	0.16 (246)	1.58 (257)	73.9 (206)
Reconditioning	1.09 (37)	0.11 (37)	1.14 (38)	68.9 (30)
	BONDED MAT OPERATIONS			
Bonded Mat	1.12 (13)	0.15 (18)	0.22 (18)	86.6 (13)
	FLAME ATTENUATED MANUFACTURING PROCESS			
Flame attenuated	1.33 (35)	0.38 (8)	0.40 (8)	89.3 (5)
	TEXTILE FORMING AND TEXTILE YARN FABRICATION AREAS			
Textile Forming	2.99 (18)	0.13 (17)	0.20 (6)	98.0 (2)
Textile Yarn Fabrication	1.19 (228)	0.37 (205)	1.50 (190)	76.9 (161)
	STAPLE FORMING AND STAPLE YARN FABRICATION AREAS			
Staple Forming	5.49 (10)	0.07 (10)	0.35 (2)	N/A
Staple Fabrication	2.25 (7)	0.11 (7)	0.20 (1)	N/A

[a] () denotes number of samples.

Source: Konzen 1974.

Dement (1973b) reported the results of extensive personal and area monitoring of airborne fiberglass concentrations at a microfiber production and filtration product plant. Sampling and analysis techniques were similar to those described by Dement et al. (1973) above. Average airborne concentrations of respirable fibers from microfiber production operations ranged from 11.8 to 12.2 fibers/cc. The average concentration of total fibers ranged from 14.3 to 14.5 fibers/cc indicating that a large percentage (over 80 percent) of the total airborne fibers were respirable.

Ottery et al. (1982) summarized fiber exposure data for 13 European manmade mineral fiber plants, three of which were textile fiberglass plants and four of which were glass wool plants. Data were characterized by job classification in a manner similar to that used by Esmen et al. (1979). Airborne fiber samples were collected on 25 mm diameter membrane filters (0.8 μm pore size). A random sample of workers in each occupational group were fitted with pumps, filters, and filter holders. The filter surface was protected by an aluminum guard to prevent contamination. Air was drawn through the filters at a rate of 2 liters per minute for 7 to 8 hours. Filters were changed when necessary to prevent overloading. Fibers were counted with an interference microscope of 500X magnification. Respirable fibers were considered to be those less than 3 μm in diameter. A minimum of 100 microscopic areas or 200 fibers were counted.

Total and respirable fiber concentrations from the four glass wool plants are summarized in Tables 16 and 17, respectively. Statistically significant differences in fiber concentrations between the various job classifications were found, production and secondary processes having higher concentrations than other classifications. However, with the exception of one unspecified secondary production process at one plant, mean respirable fiber

Table 16. Total Fiber Concentrations in Combined Occupational Groups at Four European Glass Wool Plants

Combined Occupational Groups	Total Fiber Concentration (fibers/cc) Plant O n	Plant O Mean (range)	Plant O SD	Plant F n	Plant F Mean (range)	Plant F SD	Plant L n	Plant L Mean (range)	Plant L SD	Plant B n	Plant B Mean (range)	Plant B SD
Pre-Production	5	0.01 (0.004-0.014)	0.004	8	0.005 (0.002-0.007)	0.002	5	0.007 (0.006-0.009)	0.001	5	0.01 (0.004-0.03)	0.01
Production	39	0.04 (0.01-0.46)	0.07	26	0.01 (0.003-0.02)	0.004	27	0.02 (0.006-0.07)	0.02	61	0.03 (0.003-0.16)	0.03
Maintenance	20	0.06 (0.01-0.48)	0.10	4	0.02 (0.01-0.03)	0.01	12	0.02 (0.003-0.12)	0.03	27	0.01 (0.004-0.04)	0.01
General	15	0.03 (0.01-0.06)	0.01	10	0.02 (0.01-0.03)	0.004	10	0.02 (0.01-0.03)	0.01	12	0.02 (0.022-0.07)	0.02
Secondary Process I	37	0.04 (0.01-0.12)	0.02	32	0.03 (0.01-0.14)	0.03	26	0.02 (0.003-0.05)	0.01	36	0.01 (0.002-0.05)	0.11
Secondary Process II	22	0.72 (0.12-3.13)	0.68	-	- -	-	2	0.05 (0.031-0.06)	0.02	45	0.12 (0.015-0.89)	0.11
Cleaning	-	- -	-	-	- -	-	4	0.01 (0.004-0.01)	0.04	-	- -	-

n = Number of samples.
SD = Standard deviation.

Source: Ottery et al. 1982.

Table 17. Respirable Fiber Concentrations in Combined Occupational Groups at Four European Glass Wool Plants

Combined Occupational Groups	Respirable Fiber Concentration (fibers/cc)											
	Plant D			Plant F			Plant L			Plant B		
	n	Mean (range)	SD	n	Mean (range)	SD	n	Mean (range)	SD	n	Mean (range)	SD
Pre-Production	5	0.003 (0.001-0.007)	0.002	8	0.003 (0.001-0.005)	0.002	5	0.004 (0.003-0.005)	0.001	5	0.005 (0.002-0.012)	0.004
Production	39	0.02 (0.006-0.28)	0.04	26	0.005 (0.002-0.012)	0.002	27	0.02 (0.004-0.050)	0.011	61	0.02 (0.002-0.10)	0.024
Maintenance	20	0.03 (0.003-0.27)	0.06	4	0.01 (0.006-0.03)	0.01	12	0.01 (0.001-0.08)	0.02	27	0.01 (0.002-0.03)	0.005
General	15	0.01 (0.004-0.03)	0.01	10	0.011 (0.005-0.02)	0.004	10	0.01 (0.005-0.02)	0.004	12	0.01 (0.001-0.02)	0.008
Secondary Process I	37	0.02 (0.004-0.05)	0.01	32	0.02 (0.003-0.10)	0.02	26	0.01 (0.002-0.03)	0.008	36	0.01 (0.001-0.03)	0.006
Secondary Process II	22	0.45 (0.08-1.89)	0.39	-	- -	-	2	0.03 (0.020-0.04)	0.02	45	0.07 (0.008-0.62)	0.10
Cleaning	-	- -	-	-	- -	-	4	0.005 (0.003-0.01)	0.003	-	- -	-

n = Number of samples.
SD = Standard deviation.

Source: Ottery et al. 1982.

concentrations were not greater than 0.02 fibers/cc. Total and respirable fiber concentrations from the three textile fiberglass plants are summarized in Tables 18 and 19. Again, statistically significant differences were found, and production and secondary processes again had higher concentrations than other classifications. With the exception of one unspecified primary and one secondary process, all mean respirable fiber concentrations were less than 0.01 fibers/cc. Between approximately 50 to 80 percent of the collected fibers were respirable.

b. Size Distribution of Airborne Glass Fibers

Esmen et al. (1979) in their study of fiber exposure at fiberglass and mineral wool plants, related the airborne fiber diameter distribution to the nominal diameter of the fibers being produced (see Figure 6). (Note that the nominal diameter indicates the stated size of the fiber manufactured; the actual fiber diameters are distributed around the nominal diameter.) The airborne fiber diameters decrease with decreasing nominal diameter. For a nominal diameter of 10 μm, approximately 55 percent of the airborne fibers were less than 3.5 μm in diameter. For a nominal diameter of 1.0 μm, 95 percent of the airborne fibers were less than 3.5 μm. According to the authors, the ratio of submicron diameter fibers (≤1 μm in diameter) to total fibers also varied with the nominal fiber diameter. Where primarily large diameter fibers (~6 μm and greater) were produced, this ratio was as low as 2 percent. Where fibers less than 1 μm nominal diameter were produced, the ratio was about 80 percent.

A paper presented by Dement at the 1974 NIOSH Symposium on fibrous glass (Dement 1974) presents exposure data and airborne fiber size distribution data for facilities producing large diameter and small diameter (≤1 μm) fibers. These data are categorized by product produced. Microfiber products produced

Table 18. Total Fiber Concentrations in Combined Occupational Groups at Three European Continuous Glass Filament Plants

Combined Occupational Groups	Total Fiber Concentration (fibers/cc)								
	Plant E			Plant J			Plant N		
	n	Mean (range)	SD	n	Mean (range)	SD	n	Mean (range)	SD
Pre-Production	12	0.006 (0.001-0.019)	0.005	-	- -	-	6	0.011 (0.006-0.021)	0.004
Production I	54	0.003 (0.001-0.019)	0.002	19	0.002 (0.001-0.011)	0.002	44	0.009 (0.002-0.02)	0.006
Production II	-	- -	-	32	0.002 (0.001-0.007)	0.001	22	0.033 (0.007-0.032)	0.006
Maintenance	16	0.008 (0.002-0.034)	0.006	-	- -	-	15	0.017 (0.007-0.032)	0.006
General	2	0.008 (0.008-0.010)	0.006	11	0.002 (0.001-0.004)	0.001	7	0.019 (0.010-0.032)	0.007
Secondary Process I	70	0.004 (0.002-0.034)	0.001	87	0.004 (0.001-0.015)	0.002	27	0.009 (0.005-0.020)	0.004
Secondary Process II	-	- -	-	-	- -	-	6	0.026 (0.007-0.067)	0.021
Research and Development	10	0.004 (0.002-0.006)	0.001	-	- -	-	-	- -	-

n = Number of samples.
SD = Standard deviation.

Source: Ottery et al. 1982.

Table 19. Respirable Fiber Concentrations in Combined Occupational Groups at Three European Continuous Glass Filament Plants

Combined Occupational Groups	Respirable Fiber Concentration (fibers/cc)								
	Plant E			Plant J			Plant N		
	n	Mean (range)	SD	n	Mean (range)	SD	n	Mean (range)	SD
Pre-Production	12	0.004 (0.001-0.015)	0.005	-	- -	-	6	0.009 (0.005-0.017)	0.004
Production I	54	0.002 (0.001-0.012)	0.002	19	0.001 (0.001-0.003)	0.001	44	0.007 (0.001-0.039)	0.006
Production II	-	- -	-	32	0.001 (0.001-0.003)	0.001	22	0.023 (0.005-0.112)	0.024
Maintenance	16	0.005 (0.001-0.022)	0.006	-	- -	-	15	0.014 (0.006-0.023)	0.005
General	2	0.005 -	-	11	0.001 (0.001-0.003)	0.001	7	0.012 (0.008-0.020)	0.004
Secondary Process I	70	0.002 (0.001-0.016)	0.001	87	0.002 (0.001-0.006)	0.002	27	0.007 (0.005-0.017)	0.003
Secondary Process II	-	- -	-	-	- -	-	6	0.022 (0.006-0.056)	0.018
Research and Development	10	0.002 (0.001-0.003)	0.001	-	- -	-	-	- -	-

n = Number of samples.
SD = Standard deviation.

Source: Ottery et al. 1982.

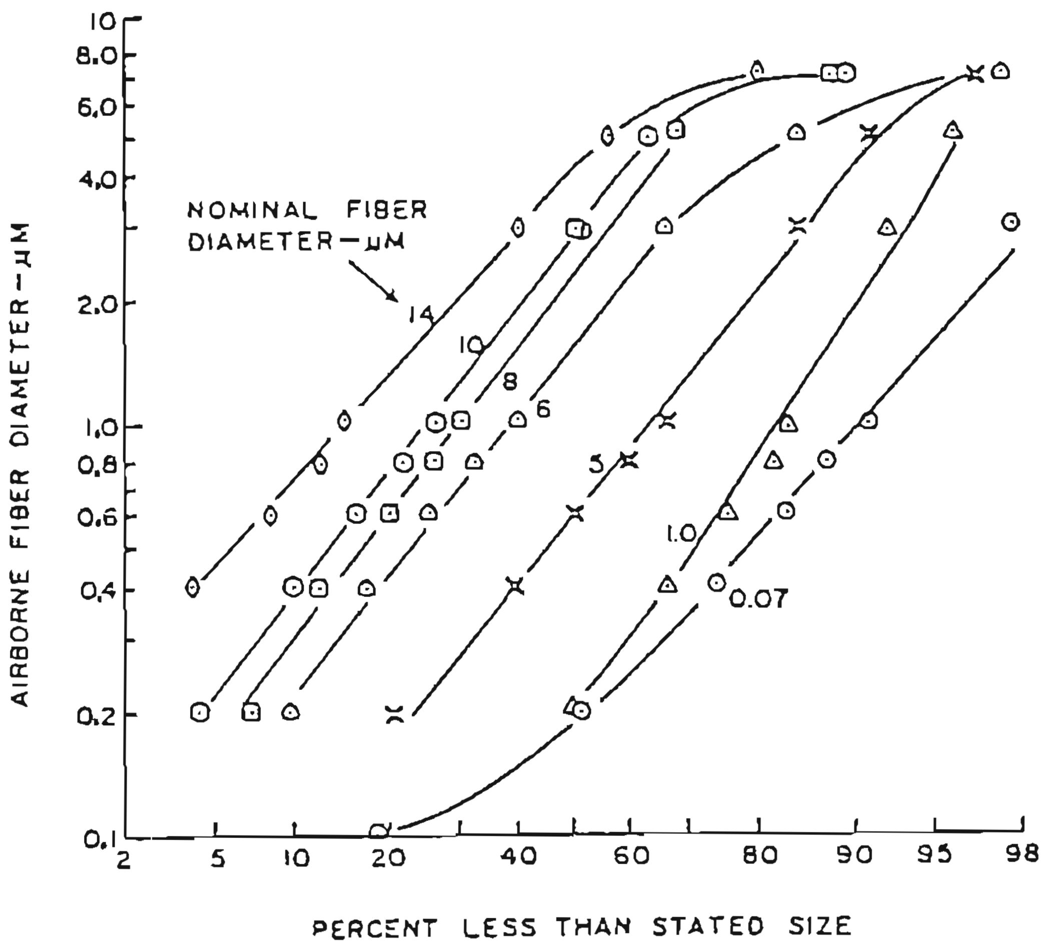

Figure 6. Airborne fiber diameter distribution, expressed as cumulative percent less than stated size, measured during production of different nominal diameter fibers. (Source: Esmen et al. 1979.)

at surveyed plants include fiberglass paper and aircraft insulation; however, only data from insulation and microfiber production facilities are presented here. Data for wool insulation appears in Table 20, and data for microfiber production appears in Table 21. The airborne fiber diameter distribution at microfiber production facilities is represented graphically in Figure 7. The nominal fiber diameters of the fibers produced are not reported in the study.

A comparison of Tables 20 and 21 illustrates that, in general, greater than 70 percent (ranging from 35-93 percent) of the airborne fibers from large diameter (≥1 μm) fiber production were less than 3.5 μm in diameter, while nearly 100 percent of the airborne fibers from microfiber production were less than 2.0 μm in diameter. One hundred percent of the fibers from microfiber production were respirable as is illustrated in Figure 7.

Corn (1974) also presented airborne fiber diameter data. These data were previously presented in Tables 6 and 7. In general, the fiber samples were less than 60 percent respirable. Higher percentages of respirable fibers were found in one of two duplicate area samples at the packing end of the reconditioning (scrap recovery) area of Plant A, in one of two duplicate samples at the bonded mat production area of Plant A (both hot and cold ends), and in the microfiber and chopped mat production areas of Plant B (cold end only). All samples taken at the bonded mat plant (Plant A) had greater than 50 percent respirable fibers; all other areas had a broader range of respirable fiber percentages. The percentage of respirable fibers found in duplicate samples was variable; no explanation is provided for this in the study.

Several of the HHE reports discussed previously present diameter distribution data for airborne fibers. A recent study of Manville Corporation's Corona, California fiberglass wool products plant (NIOSH 1984)

Table 20. Summary of Airborne Fiber Diameter Distributions as Determined by Optical Microscopy in Wool Insulation Manufacturing Facilities (Larger Diameter Glass Fibers)

OPERATION	Insulation Plant			
	A	B	C	D
Centrifugal Formed Building Insulation				
Count Median Diameter, µm	2.3	1.1	-	1.3
Percent ≤1.0 µm	10	46	-	30
Percent ≤3.5 µm	70	93	-	90
Centrifugal Formed Appliance Insulation				
Count Median Diameter, µm	-	1.1	-	-
Percent ≤1.0 µm	-	46	-	-
Percent ≤3.5 µm	-	91	-	-
Flame Attenuated Insulation				
Count Median Diameter, µm	2.8	-	1.3	-
Percent ≤1.0 µm	4	-	35	-
Percent ≤3.5 µm	60	-	58	-
Pipe Attenuated Insulation				
Count Median Diameter, µm	2.1	-	1.4	2.0
Percent ≤1.0 µm	3	-	16	15
Percent ≤3.5 µm	80	-	88	85
Scrap Reclamation	[a]			
Count Median Diameter, µm	4.3	1.3	1.9	2.1
Percent ≤1.0 µm	2	34	17	14
Percent ≤3.5 µm	35	87	70	80

[a] Scrap reclamation operations in this plant include scrap from fibrous glass textile operations.

Source: Dement 1974.

Table 21. Average Airborne Fiber Diameter Distributions as Determined by Optical Microscopy in Operations Producing Small Diameter Glass Fibers

	Percent of Fibers -- Upper Class Interval, µm							
	Bulk Fiber Handling				Fabrication and Finishing			
FACILITIES	0.5	1.0	1.9	3.8	0.5	1.0	1.9	3.8
Bulk Fiber Production								
Plant C	85	96	100	100	-	-	-	-
Plant E	72	88	95	98	76	93	98	100

Source: Dement 1974.

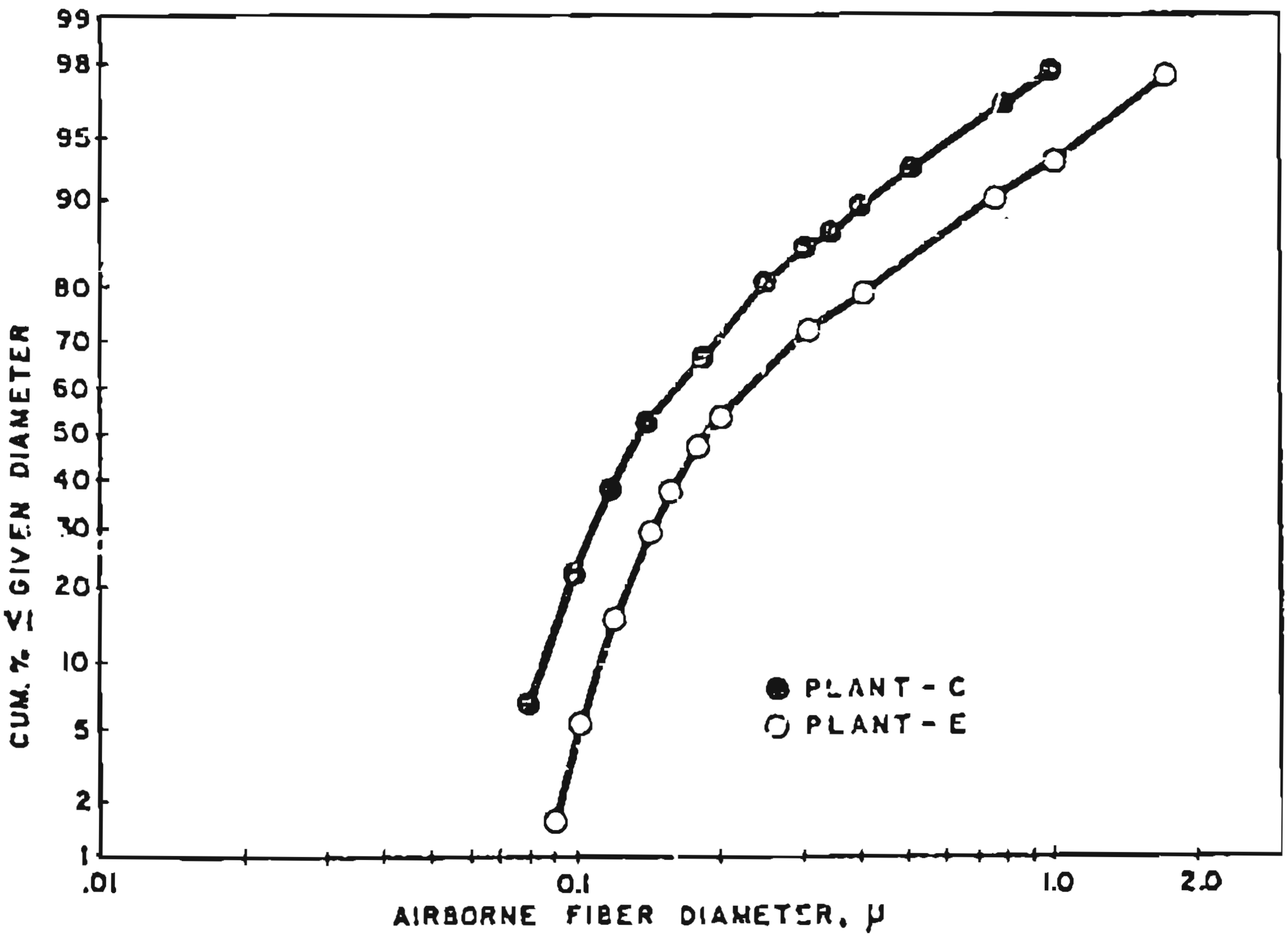

Figure 7. Airborne fiber diameter distribution for small diameter fiber production. (Source: Dement 1974.)

compared respirable and total dust concentrations. Data are presented in Tables 11 and 12. As previously discussed, respirable dusts represented a low percentage of the total dusts measured.

Older studies present fiber diameter and length distributions categorized by product manufactured and/or by fiber formation process. A study of Owens-Corning's Kansas City, Kansas plant (Dement et al. 1973) indicates that approximately 90 percent of the airborne fibers produced by the RS process (centrifugal and aerocor processes) are less than 3.5 μm in diameter (see Table 22). Airborne fibers from blowing wool operations were also approximately 90 percent respirable fibers.

Another study (Dement et al. 1972a) presented distribution data by process and product. Approximately 80 percent of the airborne fibers produced by the RS process were respirable, and about 70 percent of the fibers from the FA process were respirable. Also, about 80 percent of the airborne fibers generated from molded pipe manufacture were less than 3.5 μm in diameter. The nominal fiber diameters for products produced at this facility were not provided in the report.

4. Conclusion

In general, respirable fiber concentrations at fiberglass wool and textile fiber production facilities are less than 0.1 fibers/cc. Historically, higher fiber concentrations were found primarily in areas where there was manual handling or processing of fiberglass or fiberglass products (e.g., packers, and saw and baler operators), in areas where there is inadequate local ventilation, or in microfiber production areas. The monitoring data do not indicate any correlation between total dust levels and respiratory fiber concentrations, and respirable fibers may be only 2 percent of the total airborne dust.

Table 22. Summary of Airborne Fiber Size Data Determined by Optical Microscopy at Owens-Corning's Kansas City, Kansas Plant

Fiber Size Parameter	Aerocor	Standard Insulation	Aerocor Fabrication	Blowing Wool
Diameter				
Median Diameter, μm	1.1	1.1	1.1	1.3
Geometric Standard Deviation, μm	2.0	2.4	2.9	2.4
Percent Fibers ≤3.5μm	93	91	85	86
Length				
Median Diameter, μm	26	19	23	22
Geometric Standard Deviation, μm	4.9	3.0	4.3	5.1
Percent Fibers ≤50μm	68	80	71	69

Source: Dement et al. 1973.

Fiberglass production operations have become increasingly automated in the past 15 years in many areas. Automation has changed the exposure characteristics of production line workers by either removing the worker from the exposure area, or by mitigating or eliminating the source of potential exposure. Airborne fiber generation is generally well controlled as a natural consequence of the forming and curing operations. In fabrication and finishing areas where the potential for exposure is higher, local ventilation is used to control airborne fiber levels. In general, potential exposure to resin and binder compounds (e.g., formaldehyde) and free silica (from raw material operations) have been a greater concern than fiber exposure in fiberglass plants.

Literature and industry sources have claimed that airborne fiber concentrations resulting from textile fiber operations are much lower than those resulting from fiberglass wool operations and are, therefore, less of a concern from an environmental and health standpoint. Although this conclusion is expected based on the differences in the two production processes, the limited amount of data obtained for textile fiber production does not support this conclusion; the data indicate that airborne fiber concentrations are comparable during the production of both wool and textile forms of fiberglass. Mean reported concentrations for both types of fibers are generally less than 0.1 fibers/cc and often less than 0.05 fibers/cc. At these low concentrations, any variability in concentrations between job classifications or fiber types may be masked by the inherent variability in day-to-day fiber production rates at the same location (Owens-Corning 1986b). This is supported by the relatively large variability in reported concentrations of duplicate samples within some studies. Fiber concentrations are generally one or two orders of magnitude below the applicable fibrous dust standard of 3 fibers/cc.

Available data indicate that fiber concentrations from the production of microfibers (those less than 1 μm in diameter) can result in significantly higher airborne fiber exposures and higher percentages of respirable fibers than the production of standard products; several studies have shown more than an order of magnitude increase in airborne fiber exposure levels compared to those for standard fiber production operations. Mean fiber concentrations as high as 10 fibers/cc have been reported in the literature for microfiber production operations.

It can be expected, based on available data, that greater than 50 percent of the total airborne fibers will be respirable. The data, however, are highly variable. Airborne fiber size distribution is related to the nominal diameter of the fibers being produced or processed, and a much higher percentage of respirable fibers can be expected at facilities producing small diameter fibers. In facilities producing fibers less than 1 μm in nominal diameter, 90 percent of the airborne fibers may be less than 1 μm in diameter. It should be noted, however, that small diameter fibers are used primarily in specialty products (e.g., aircraft and high-temperature insulation, filters, and fiberglass paper) which have a much lower production volume (and lower number of potentially exposed workers) than standard textile fiber and insulation products.

B. Fiber Use

Fiberglass wool is used primarily to manufacture thermal insulation products for residential, industrial and commercial applications. Fiberglass wool is also used to manufacture acoustic tile, ductboard, filters, fiberglass mat, and specialty products (EPA 1983, ICF 1986, Barnhart 1974). A summary of the major uses of fiberglass wool is presented in Table 23.

Textile fibers are used as manufactured or are cut into short lengths to make "chopped strand" fiberglass. Continuous filament and chopped strand are used primarily as reinforcement materials (e.g., in fiberglass reinforced plastic products). Textile fiberglass is also used in the manufacture of industrial fabrics, roofing material, electrical insulation, and specialty products (Owens-Corning 1983, PPG 1984, ICF 1986, Barnhart 1974). A summary of the major uses of textile fiber appears in Table 24.

Investigation of the manufacture of primary fiberglass products (textile fiberglass and standard insulation products) indicated that the manufacture of these products does not present a significant worker exposure hazard. Several studies (e.g., Esmen et al. 1979a, Dement 1973a, Dement 1973b) have shown that the manufacture of specialty products,, particularly fine fiber and microfiber products,* has the potential to generate relatively high airborne fiber concentrations. Aircraft insulation is a fine fiber product. Microfiber products include fiberglass paper and filtration products. The manufacturing processes and exposure potentials for fiberglass paper and aircraft insulation production are discussed in Sections B.1 and B.2 of this chapter, respectively. Production of blowing wool was previously discussed in Section A, Fiberglass Production.

The installation of both standard and fine fiber insulation products has been shown to have a relatively high exposure potential if ventilation in the insulation area is poor (Fowler et al. 1971, Esmen et al. 1982, Head and Wagg

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* Fine fiber products have a nominal fiber diameter on the order of 1 μm. Microfiber products have a nominal fiber diameter less than 1 μm.

Table 23. Uses of Fiberglass Wool

A. Structural Insulation

   1. Private Residences

      a. Retrofits of Existing Structures
      b. New Homes

   2. Commercial

   3. Industrial

B. Industrial and Equipment Insulation

   1. Heating Equipment

   2. Cooling Equipment

   3. Tanks and Storage Facilities

   4. Transportation Equipment

      a. Automobiles
      b. Marine
      c. Aerospace

C. Pipe and Duct Insulation

D. Acoustic Tile

E. Fiberglass Mat

F. Filtration

Source: ICF 1986.

Table 24. Uses of Textile Fiberglass

A. Reinforced Plastics

1. Aircraft/Aerospace
2. Appliances and Equipment
3. Construction
4. Consumer Goods
5. Corrosion-Resistant Products
6. Electrical Equipment
7. Marine Products and Accessories
8. Automotive, Truck, and Motor Home Parts
9. Equipment for Material Handling, Protective Gear, Farming, and Industrial Tooling

B. Textiles

1. Yarns

    a. Paper and Tape Reinforcing
    b. Thread
    c. Electrical Cable Braiding and Wrapping

2. Fabrics

    a. Circuit Boards
    b. Orthopedic Casts
    c. Industrial Fabrics
    d. Decorative Fabrics
    e. Filtration
    f. High Temperature Fabrics
    g. Roofing Materials

3. Abrasives

4. Fiber Optics

    a. Decorative
    b. Light/Image Transmission
    c. Communications

Source: ICF 1986.

1980). Removal of insulation products from existing structures, such as in building renovation/demolition and in refitting of industrial installations, has also been shown to have a significant potential for exposure, particularly for very old installations where no binder was used in the insulation product (Schneider 1979, Schneider 1982). The installation of insulation products is discussed in Section B.3 of this chapter.

Nominal fiber diameters for standard insulation products range from 1.5 µm to 15 µm. Specialty fine fiber products such as aircraft insulation are made from fibers which are approximately 1 µm in diameter. Microfiber products such as fiberglass paper and filtration products are manufactured from fibers less than 1 µm in diameter. Blowing wool, including Insulsafe® manufactured by Certain-Teed, is manaufactured as loose wool fibers; these fibers are similar in diameter to those used to manufacture standard insulation products.

1. Manufacture of Fiberglass Paper and Filtration Products

Fiberglass paper is manufactured from bulk fibers by a process similar to that used to make conventional cellulose paper. The bulk fiber used in the process is generally less than 1 µm in nominal diameter, and the handling of such fibers represents a potential exposure point. Also, the fabrication of finished products (e.g., vacuum cleaner bags and oil, fuel and air filters) from fiberglass paper can also generate airborne fibers.

Fiberglass paper is a specialty product, and manufacturers of fiberglass paper generally manufacture other types of specialty papers as well. Paper manufacturers may manufacture more than one type of paper on a particular machine. Approximately 5 million pounds of fiberglass paper is produced annually in the U.S. (Hollingsworth and Vose 1986a, Considine 1983).

Filtration products are manufactured from fiberglass paper or directly from microfiber fiberglass mat, by either primary or secondary producers. The fabrication of these products, particularly cutting operations, can also generate airborne fibers. Filtration products are also specialty products and are manufactured in small quantities. Fiberglass paper and other fine fiber/microfiber fiberglass products represent less than 1 percent of all fibrous glass production in the U.S. (Konzen 1982).

The number and names of companies who manufacture fiberglass paper and filtration products is not currently available.

a. Manufacturing Process/Potential Exposure Points

(1) Process Description and Automation

Specialty paper is produced from several different fibers including fiberglass, aramid, polyolefin, and ceramic fibers. The basic paper manufacturing process is the same for any of the fibers used and involves the following steps:

- Batch mixing of fibers and other raw materials;
- Mixing with water to form pulp;
- Formation of continuous pulp mat on wire screen;
- Removal of water from mat by vacuum;
- Drying of mat on steam heated rollers;
- Application of binder to paper;
- Final drying on steam heated rollers;
- Winding;
- Cutting and rewinding for packaging or
- Cutting and secondary fabrication; and
- Scrap recovery (shredding, heat treatment, recycling).

These process steps are illustrated schematically in Figure 8.

The paper manufacturing process is a semi-batch operation, involving batch mixing of raw materials followed by continuous paper manufacture. Raw materials are weighed and batch mixed in a blender referred to as a beater. Raw fibers may be delivered in boxes, bags, or bales. If pulpable bags or

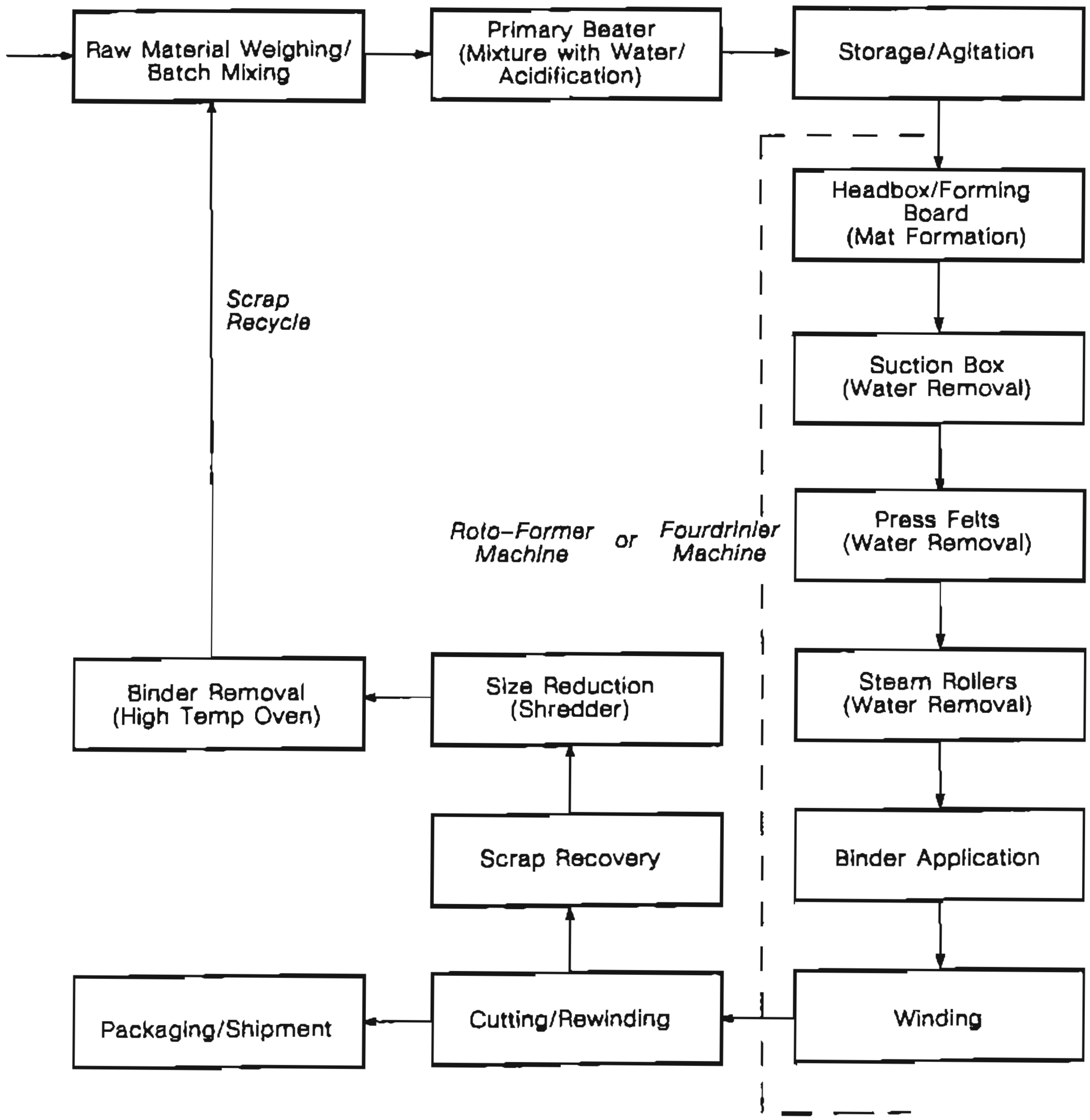

Figure 8. Paper manufacturing process flowsheet.

boxes are used, the entire box or bag may be added to the beater unopened. In other cases, the box or bag is cut open by an operator, and the raw fibers are manually added to the beater.

After being mixed with water in the beater, the pulp is pumped to an agitated storage tank where additives and pulp conditioners may be introduced. The pulp is then pumped into the head box of a continuous paper forming machine (either a roto-former or a fourdrinier machine) and distributed across a moving wire screen to form a continuous mat. The fourdrinier machine is illustrated in Figure 9. Roto-former or cylinder machines, in which a wire screen on a rotating cylindrical mold is submerged in the pulp vat, are also used in paper manufacture particularly for multi-ply board, but are less common than fourdrinier machines. Any type of pulpable fiber can used on any machine, and different grades and thicknesses of paper can be made by adjusting the machine.

The continuous mat formed on the wire screen is conveyed through a sunction box, in which water is removed from the mat by vacuum, or a wet box, in which water is removed by mechanical action. Additional water is removed from the mat by compression between rollers and by drying on a series of steam-heated rollers. Binder is applied to the partially dried paper, and the paper is then further dried on a second series of steam-heated rollers. The finished paper is wound onto rolls and cut from the machine. The paper is then rewound for packaging and shipment or for further fabrication into finished products (Considine 1983, Hollingsworth and Vose 1986a, Lydall 1986a, Dement and Bierbaum 1973a).

Rolls of finished paper are cut from the machine and removed manually for packaging or further processing. Papermaking operations are continuously

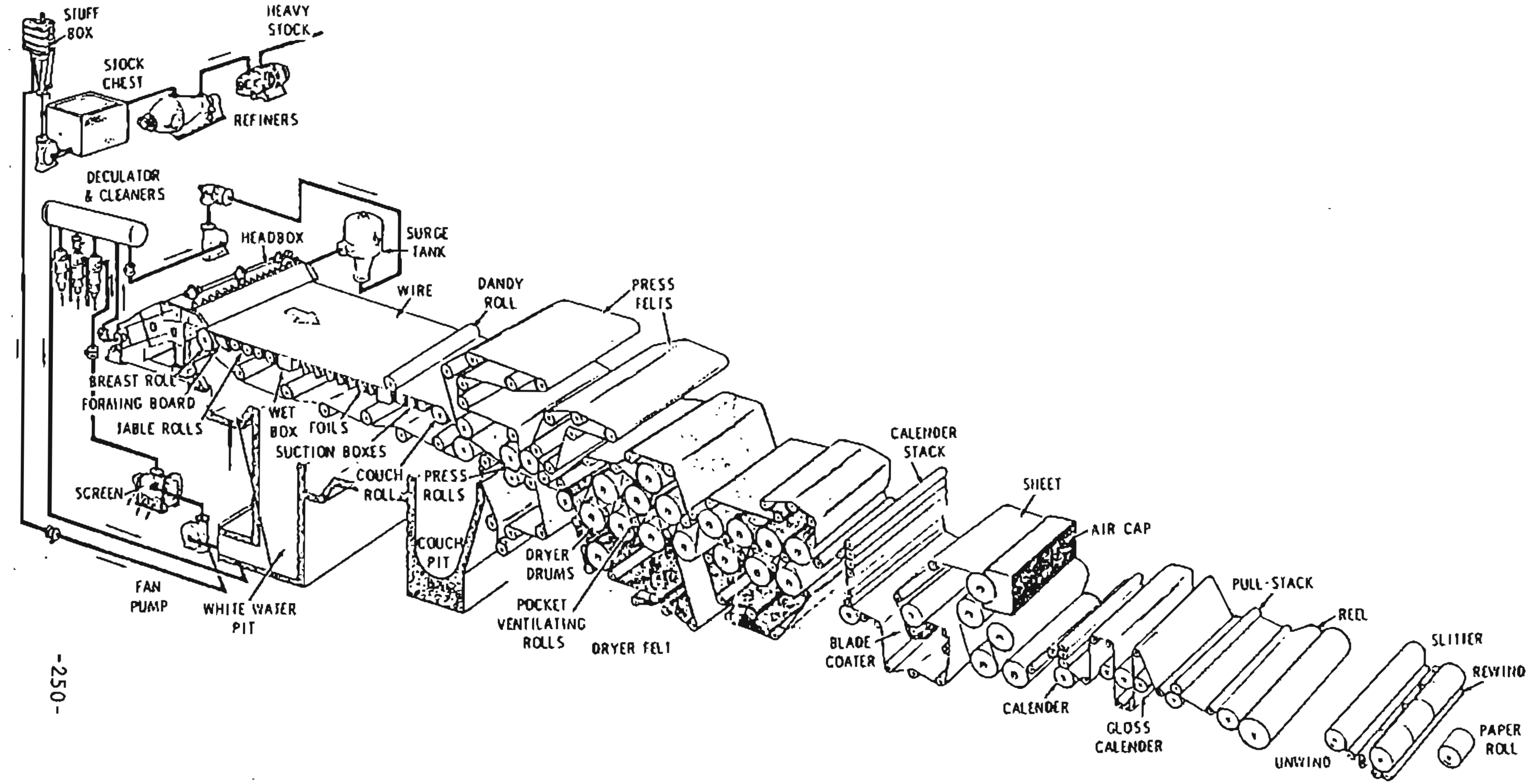

Figure 9. Fourdrinier machine for producing printing-grade paper. (Source: Beloit Corporation.)

operated throughout the year, but papers other than fiberglass paper may be made in these same facilities.

The raw material handling operations in the beater area and the cutting operations to remove the finished paper from the machine have the potential to generate airborne fibers. Secondary fabrication of the paper into finished products, which may involve additional cutting of the paper, may also generate fibers. The continuous portions of the process (pulping, mat formation, and drying) are wet operations which do not generate fibers. Fibers are not generated in the beater area if pulpable bags are used.

(2) Engineering Controls and Protective Equipment

Local ventilation is used primarily in batch or manual areas of the process. In the raw materials handling and beater room areas and in areas where the finished paper is cut or fabricated into products, local ventilation is recommended by some manufacturers (Hollingsworth and Vose 1986b), but is not used by all manufacturers. The fiberglass scrap recovery area may also be enclosed and/or ventilated (Dement and Bierbaum 1973a). Dust masks may be available, but are not always required by employers or worn by employees. Some manufacturers require the use of dust masks during dusty operations (Lydall 1986a, Hollingsworth and Vose 1986a).

b. Extent of Potential Exposure

(1) Number of Persons Exposed

Approximately 8 to 10 workers are required to operate a papermaking machine:

- 1 Receiver -- unloads raw materials;
- 2 Beater operators -- add raw material to pulper;
- 4 or 5 paper machine operators -- 1 machine tender, 1 back tender, and 2 or 3 extras; and
- 1 or 2 packaging workers.

Additional workers are involved in secondary fabrication (if any), maintenance, and quality control operations (Lydall 1986b, Hollingsworth and Vose 1986a).

(2) Exposure Levels/Respirability of Airborne Fibers

Several studies present exposure data for the manufacture of fiberglass paper and fiberglass filters. Dement and Bierbaum (1973a) reported fiber concentrations at Dexter Corporation's fiberglass paper manufacturing facility. Four air samples (3 personal and 1 stationary) were taken to determine airborne fibrous glass fiber exposures by fiber counts using optical microscopy. These samples were collected on Type AA 37mm membrane filters at a sampling rate of 2.0 liters/minute. The sampling times varied in duration from approximately 16 minutes to 99 minutes.

Collected samples were analyzed for fiber concentration by an optical count method similar to that used for asbestos. Due to the presence of very small diameter fibers, these counts were done with an oil immersion phase contrast objective at 1000X magnification. Fiber diameter distributions also were determined for each sample. The method used for distribution determination was not discussed.

Airborne fiber concentrations measured for breathing zone samples ranged from 10.6 fibers/cc to 44.1 fibers/cc; the data are summarized in Table 25. The beaterman who adds the fibers and other raw materials to the beater is exposed to the highest concentration of airborne fibers. The winder operator who cuts off rolls of paper and transfers them to the packaging or fabrication areas is exposed to the next highest concentration of airborne fibers. Table 26 provides the median diameters of the grades of fiberglass used in this

Table 25. Airborne Fiber Concentrations -- Paper Manufacturing at the C.H. Dexter Division of Dexter Corporation

Job Classification	Fibers/cc	Percent Respirable
Beaterman	44.1	97%
Beaterman	12.6	87%
Winder Operator	10.6	86%
Mixing Tank (Area Sample)	8.9	76%

Source: Dement and Bierbaum 1973a.

Table 26. Fibrous Glass Fiber Diameters Used for Making Filtration Paper and Cryogenic Insulation by the C.H. Dexter Division of Dexter Corporation

Fiber Designation	Median Fiber Diameter, μm
102	0.20
104*	0.50
106*	0.75
108	1.60
110*	2.60

* These fibers are the major categories which are used in this facility.

Source: Dement and Bierbaum 1973a.

paper manufacturing operation. Median fiber diameters used to manufacture filtration paper range from 0.2-2.6 μm. Since such fine diameter fibers are used to manufacture the paper, the percentage of respirable airborne fibers is high (86-97 percent) as shown in Table 25. Local ventilation at this facility was provided only at the binder application and steam roller drying areas of the paper machine to control binder fumes. The fiberglass shredder was enclosed and locally ventilated.

Dement (1973a) also reported airborne fiber concentrations for another paper manufacturing facility using fibers ranging from 0.05 to 3.8 μm nominal diameter; the exposure data are summarized in Table 27. Sampling techniques were similar to those described by Dement and Bierbaum (1973a) above. Sample duration was between 4 and 7 hours. Fiber diameter distributions were determined by electron microscopy; at least 100 fibers were sized for each sample. The beaterman is again exposed to the highest airborne fiber concentrations, 4.7-6.8 fibers/cc, of which 72 percent is respirable. The paper folder and saw operator are exposed to concentrations less than 3 fibers/cc, but 90 percent of the airborne fibers are respirable. Local ventilation was not provided in the raw material weighing and mixing areas.

Hammad and Esmen (1982) provide fiber concentration data from two surveys of a microfiber production facility manufacturing filter tubes. Concentrations were measured using phase contrast (optical) microscopy. Sampling and analysis techniques were the same as those used by Esmen, et al. (1979) and were described in the previous section. Fibers produced at the plant ranged from 0.05 to 1.6 μm in nominal diameter. Filter tubes are manufactured from fiberglass mat by a process similar to that used for pipe insulation. The tubes are finished by cutting to the desired length, placed in a cover (socking), and packaged (Dement 1973b). The mean fiber concentration in the

Table 27. Airborne Fiber Concentrations -- Paper Manufacturing Facility

Job Classification	Fibers/cc	Percent Respirable
Beaterman	4.7	72%
Beaterman	6.8	72%
Paper Folder	2.1	90%
Saw Operator	1.6	90%

Source: Dement 1973a.

first survey was 0.26 fibers/cc; the second survey showed a mean concentration of 2.45 fibers/cc (only three samples were taken). No data on the quality of ventilation were provided. Mean fiber concentrations in the microfiber production area ranged from 0.10 fibers/cc to 5.8 fibers/cc. Considering that the fiber sizes produced at the plant are less than 1.6 µm in nominal diameter, it is likely that close to 100 percent of the airborne fibers were respirable.

The authors report that the ratio of airborne fiber concentration measured by optical microscopy (OM) to that measured by electron microscopy (EM) was 0.14 for the microfiber facility, ranging from 0.08 to 0.50 (25/75 percent quartiles). OM measures fibers greater than 1µm in diameter while EM measures fibers less than 1 µm in diameter; EM analysis is not normally used in industrial hygiene surveys because of its high cost. To determine the total number of airborne fibers, the OM and EM concentrations must be added. This indicates that the total number of airborne fibers may be 2 to 12 times the number of fibers actually measured by OM. However, individual EM measurements are not reported, and the range of total fiber concentrations cannot be determined from the OM data presented.

Riedeger (1982) reports OM and EM fiber concentration data for the finishing of fiberglass respirator filters. A Gravikon VC 25 G dust sampler was used for sampling total dust, with an intake velocity of 1.25 meters/sec. Respirable dust, was sampled by the Gravikon VC 25 F. Both instruments are static samplers which use membrane filters with pore size 8 µm. The flow rate was maintained constant during the sampling period to 22.5 m^3/hour. The sampling periods varied between 1/4 and 4 hours.

The VC 25 G's samples were prepared for examination by EM. The method used was to cut between 5 cm^2 and 50 cm^2 (depending on the particle density on the filter) out of the membrane filter used in the VC 25 G, dissolve it in acetone, and filter the particles out onto a new filter. The filter was dried and sputtered with gold before it was examined by EM. The magnification for measuring the fiber diameter was generally between 2000X and 5000X, but it was often necessary to reduce the magnification to measure the length of the same fiber, in a few cases, down to 50X. A sufficient number of photomicrographs were taken, spread evenly over the specimen, so that for most of the filters many more than 100 fibers (up to 600) could be measured for length and diameter. Photomicrographs were taken even for those fields in which no fiber could be detected on the screen; often the photomicrograph showed more or less fine fibers. Fiber diameter was measured by means of a graticule magnifier with magnification 30X and a ruler subdivided at 0.05 mm intervals.

In addition to the EM analysis of dust samples taken with static samplers, personal samples were taken for fiber counting with the phase contrast light microscope. An SSG personal sampler was used which incorporates a small rotary pump in the sampling head with a replaceable filter holder, which is an open- faced aerosol monitor. Membrane filters are used with mean pore size 0.8 μm and effective filtering area 8.55 cm^2. The flow rate was 2 liters per minute. The sampling periods were 1 hour in most cases. The membrane filters were made transparent and examined with a phase contrast microscope (objective 40X, ocular 10X). All fibers longer than 5 μm, thinner than 3 μm, and with an aspect ratio greater than 3 were counted. Counting was continued until a maximum of 100 fields were examined or until 100 fibers were counted.

Concentrations measured by OM ranged from 0.1 to 0.2 fibers/cc; concentrations measured by EM ranged from 0.6 to 2.6 fibers/cc. Airborne fiber size distribution data are illustrated in Figure 10. Over 90 percent of the fibers were less than 3.5 μm in diameter (i.e., respirable), and the median fiber diameter was 0.7 μm.

Dement (1973b) reported the results of extensive personal and area monitoring of airborne fiberglass concentrations at a microfiber production and filtration product plant. Eight stationary sample sites were chosen and sampled for three consecutive days. All samples for fiber count were collected on 37 mm diameter Type AA cellulose ester membrane filters (0.8 μm pore size) at a sampling rate of 2 liters/minute with an open filter face.

Laboratory analysis of the collected fiber count samples was done by an optical count method similar to that described by Dement and Bierbaum (1973d). In addition to size distributions determined by optical microscopy, fiber size distributions were determined for four of the microfiber personal samples with higher fiber concentrations using transmission electron micrographs and a "Zeiss" particle size analyzer at a total magnification of 14,465X (including photographic enlargement). Photomicrographs also were made of these four samples.

Average airborne concentrations of respirable fibers from microfiber production operations ranged from 11.8 to 12.2 fibers/cc. The average concentration of total fibers ranged from 14.3 to 14.5 fibers/cc indicating that a large percentage (over 80 percent) of the total airborne fibers were respirable.

c. Conclusion

Available data indicate that airborne fiber concentrations for fiberglass paper and filtration product manufacture can be an order of magnitude higher than concentrations resulting from the fabrication of

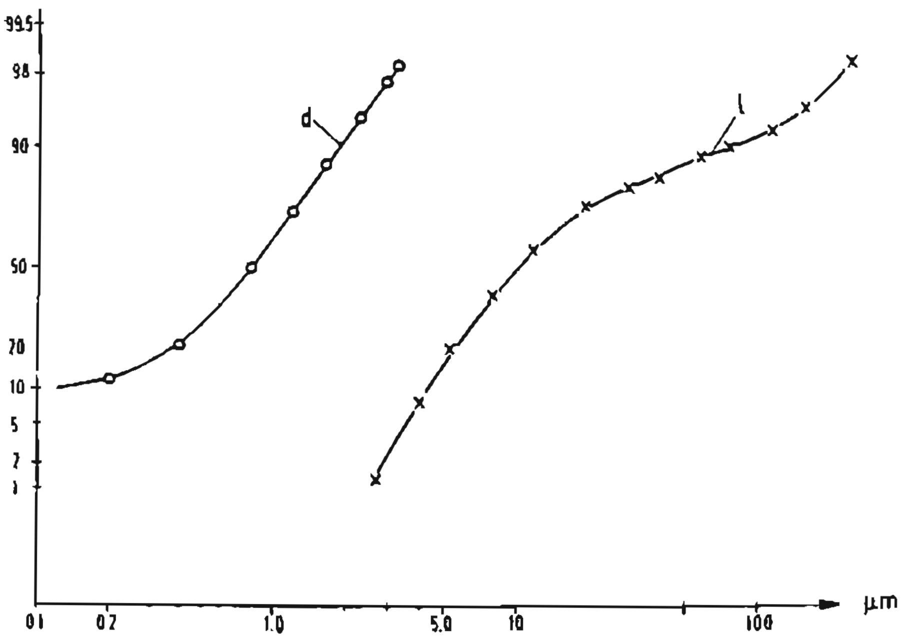

Figure 10. Distribution of fiber length and diameter for cutting glass fiber filters. (Source: Riediger 1982.)

standard insulation products. Principal exposure points are the raw materials handling and product cutting and finishing areas. Both fiberglass paper and filtration products are generally manufactured from fine fibers and/or microfibers, and the airborne fibers may, therefore, be more than 90 percent respirable and more than 50 percent less than 1.0 μm in diameter. Airborne fiber concentrations appear to be highly dependent on the quality of local ventilation in the fiber generation areas.

Microfiber products represent less than one percent of all fiberglass production in the U.S. and are considered specialty products by the industry. Production of these products involves comparatively few workers, some of which, however, are involved in manual operations resulting in relatively high potential for exposure. The data indicate that use of local ventilation will significantly decrease the exposure of workers to fibrous glass.

2. Manufacture of Aircraft Insulation

Aircraft insulation is a fiberglass mat product similar to residential insulation, except that it is of much lower density and is manufactured from fine diameter fibers (~1 μm in diameter). The manufacture of aircraft insulation has been shown to have the potential to generate high concentrations of respirable fibers (Dement and Bierbaum 1973b, Dement 1975). Studies also indicate that nearly 100 percent of the airborne fibers generated from aircraft insulation manufacture are respirable and 90 percent are less than 1.0 μm in diameter (Esmen et al. 1982, Dement 1973c). Aircraft insulation manufacture is generally a bench-type operation, where manual handling of the fiberglass and manual operation of machinery are required. As expected, the quality of ventilation is an important parameter in minimizing airborne fiber concentrations, and application of local ventilation has been recommended to reduce exposure levels (Dement and Bierbaum 1973b, Dement

1973c). The fine airborne fiber size, manual handling of the fiberglass, and the high potential for fiber generation can result in the manufacture of aircraft insulation being a significant exposure hazard.

Some of the primary fiberglass producers and some small firms manufacture aircraft insulation. We are continuing research into the number and names of companies who manufacture aircraft insulation.

a. Manufacturing Process/Potential Exposure Points

(1) Process Description and Automation

The manufacture of aircraft insulation is primarily a fabrication process which involves the following steps:

- Delivery of aircraft-grade fiberglass mat (cured or uncured);
- (Curing fiberglass mat in oven);
- Manual or automatic cutting of mat on forming tables;
- Application of metallized covers to mat;
- Manual or automatic sewing or quilting of covers to mat; and
- Cutting and packaging finished aircraft insulation.

Fiberglass blankets with nominal fiber diameters on the order of 1 μm are received from a primary production facility. The binder coated blanket may be cured at the primary production facility or by the aircraft insulation manufacturer. The blanket is then placed between metallized covers, which are sewn into place by automatic sewing machines, forming a continuous blanket. The blanket is then cut into the required length by hand or with a band saw. Irregular shaped pieces are fabricated by hand by placing fiberglass blankets on tables with precut templates and cutting them with a power saw. The covers are then sewn on using a sewing machine. Fabrication of irregular shaped insulation is a more manual operation than the fabrication of continuous blanket. The fibrous glass is completely encased by the covering and presents no exposure hazard during its installation (Dement 1973c, Esmen et al. 1982, Hitco 1986).

(2) Engineering Controls and Protective Equipment

The manufacture of aircraft insulation is considerably less automated than the manufacture of standard insulation products, and involves manual cutting and shaping of fine fiberglass mats, which creates a significant exposure potential. Local ventilation may be applied to control airborne fiber levels in mat cutting areas; airborne fiber concentrations may be unacceptably high otherwise. Filter masks are generally made available to aircraft insulation workers; however, it is not known to what extent they are actually used. Several studies have recommended that respiratory protection be required for aircraft insulation workers handling bulk fiberglass mat, but workers probably do not use them (Dement 1973c, Dement and Bierbaum 1973b).

b. Extent of Potential Exposure

A study of airborne fiber concentrations at aircraft insulation facilities (Dement 1973c) found generally low concentrations in most areas of the process. The study, however, indicated that the facility lacked adequate ventilation and that application of local ventilation could significantly reduce exposure levels which were relatively high in some areas. Personal and general area samples (46 total) for airborne fibrous glass were collected in the various fibrous glass operations for evaluation by fiber count.

Personal and stationary samples were taken by placing a pump on each worker or at each sample site. Filters on the fiber count samplers were changed periodically such that fiber concentrations did not become so high as to hinder counting. Sampling and analysis of the collected fiber count samples was done by an optical count method similar to that described by Dement and Bierbaum (1973a).

The fiber concentrations were generally below 3 fibers/cc, with more than 80 percent of the samples below 1.5 fibers/cc. The highest concentration (4.4 fibers/cc) was experienced by the quilting machine operator. The next highest airborne fiber concentrations were experienced by the pattern cutter (2.2-3.1 fibers/cc). (One pattern cutter sample yielded a lower exposure level of 0.6 fibers/cc; no information on work practices was supplied to explain this large difference in exposure from other reported values.) More than 90 percent of the fibers were found to be respirable in most of the samples. The data are summarized in Table 28.

Dement and Bierbaum (1973b) provided exposure data for a defense products facility fabricating fiberglass insulation. Three personal samples were taken in the fabrication area; sampling duration was from 40 to 46 minutes. Sampling and analysis procedures were similar to that described in Dement and Bierbaum (1973a). Data are summarized in Table 29. The highest concentration obtained was 24.4 fibers/cc for a worker laminating glass insulating bats to form thicker bats. A total fiber concentration of 14.8 fibers/cc was observed for the "band saw operator and oven tender," and a concentration of 3.2 fibers/cc was observed for a fibrous glass press operator. Local ventilation was not applied in the fabrication areas. Between about 80 and 100 percent of the fibers were respirable. According to Hitco representatives, the band saw operation was conducted in a completely enclosed environment (a polyethylene tent) to control dust emissions, and respiratory protection was required for the operator. The band saw process has since been shutdown (Hitco 1986b).

Table 28. Airborne Fiber Concentrations -- Aircraft Insulation Manufacture at the Hitco Facility in Atlanta, Georgia

Job Classification or Area Description	Fibers/cc	Percent Respirable
Fiber Mat Cutting		
Pattern Cutter	3.1	94%
	2.9	93%
Pattern Cutter	0.6	83%
	2.2	95%
Cutting Table (Area Sample)	0.5	~100%
	0.6	~100%
Cutting Table (Area Sample)	1.7	94%
Cutting Table (3 ft. Distance)	0.4	~100%
	0.5	~100%
Cutting Table (3 ft. Distance)	0.5	~100%
Cutting Table (7 ft. Distance)	0.6	~100%
Rollout Table (4 ft. Distance)	1.4	~100%
Mat Trimmer	1.1	91%
Foil Insulation Assembly		
Fiber Cutter/Stuffer	1.0	90%
	0.4	~100%
Fiber Cutter/Stuffer	0.4	75%
	0.5	80%
Fiber Stuffing (2 ft. Distance)	0.4	~100%
	0.3	~100%
Fiber Stuffing Table (Area Sample)	0.5	80%
Fiber Stuffing Table (Area Sample)	0.2	~100%
Fiber Stuffing Table (Area Sample)	0.5	80%
Fiber Stuffing Table (Area Sample)	1.1	91%

Table 28 (Continued)

Job Classification or Area Description	Fibers/cc	Percent Respirable
Quilting/Sewing		
Quilting Machine Operator	4.4	86%
	0.7	57%
Quilting Machine (Area Sample)	0.7	~100%
	0.3	~100%
Sewing Table (Area Sample)	0.2	~100%

Source: Dement 1973c.

Table 29. Airborne Fiber Concentrations -- Aircraft Insulation Manufacture at the Hitco Facility in Gardena, California

Job Classification or Area Description	Fibers/cc	Percent Respirable
Band Saw Operator	14.8	83%
Glass Bat Lamination	24.4	89%
Fibrous Glass Press Operator	3.2	97%

Source: Dement and Bierbaum 1973b.

Esmen et al. (1982) also provided exposure data for two aircraft insulation manufacturing facilities. Sampling and analysis procedures were similar to those described by Esmen et al. (1979) above. Exposure levels are similar to those reported by Dement (1973c), and the percent of respirable fibers ranges from 93-99 percent for all samples. The data are summarized in Table 30. The highest airborne fiber concentration was found at the mat cutter (1.7 fibers/cc average, 3.78 fibers/cc high). Fiber concentrations were less than about 1.0 fiber/cc at all other locations sampled. The authors do not provide detailed descriptions of the local ventilation in the facilities.

c. Conclusion

As was the case for fiberglass paper and filtration products, nearly 100 percent of the airborne fibers measured in aircraft insulation manufacturing operations are respirable. Airborne fiber levels are much lower than those found in paper manufacture, however; fiber concentrations are of the same order as those found for the production of standard insulation products. Aircraft insulation is a specialty product, and all manufacturing installations for which exposure data were found employed less than 100 people; all workers are directly involved in the fiberglass processing and work 8-hour shifts. Aircraft insulation manufacture is a manual process, and there are several potential exposure points including cutting and sewing operations, which may require local ventilation.

3. Installation and Removal of Insulation Products

Several studies have been conducted on the exposure of insulation workers to man-made mineral fibers (primarily fiberglass and mineral wool) both in the U.S. and in Europe (Esmen et al. 1982, Head and Wagg 1980, Apol et al. 1980, Schneider 1979, Fowler et al. 1971). The study of worker exposure

Table 30. Airborne Fiber Concentrations -- Aircraft Insulation Manufacture

Job Classification	Number of Samples	Fibers/cc Average[a]	Fibers/cc Range	Percent Respirable
Sewer Plant A	16	0.44	0.11-1.05	98%
Plant B	8	0.18	0.05-0.26	96%
Cutter Plant A	8	0.25	0.05-0.58	98%
Plant B	4	1.70	0.18-3.78	99%
Cementer Plant A	9	0.30	0.18-0.58	94%
Plant B	1	0.12	--	93%
Isolated Jobs Plant A	7	0.24	0.026-0.31	99%
Plant B	3	0.05	0.012-0.076	94%

[a] Arithmetic mean.

Source: Esmen et al. 1982.

in installation/removal of insulation products is more complex than exposure studies of production processes, and the exposure levels cannot easily be compared for several reasons. The exposure characteristics of insulation workers are much different than those of production workers. An insulation worker may install a variety of insulation products at different locations at a jobsite on a particular day. At a residential site, for example, low density batts (wall and floor insulation), high density board (ceiling insulation), pipe insulation, and ductwrap may all be installed in different areas of the site. A single worker may fabricate, apply, and finish an insulation piece and then move to a different area of the site, or the worker may remain at the same job throughout the day (Fowler et al. 1971, Fisher 1986, Esmen et al. 1982). Different products and operations have different exposure potentials. Several studies indicate that insulation workers are not continuously exposed for the entire workday and may be subject to exposure from several different insulation products at the same job site (Esmen et al. 1982, Schneider 1982). Production facility workers, with the exception of maintenance workers, would generally be exposed to a less variable environment, as there would be fewer changes in job type and location for each worker. Also, the level of ventilation at a job site, a critical parameter in controlling airborne fiber concentrations, is much more variable than at a production facility. The insulation worker may not work exclusively with fiberglass insulation, particularly at industrial jobsites where ceramic, mineral wool, or asbestos insulation may also be in use (Fowler et al. 1971). Insulation workers at residential jobsites, however, would be exposed primarily to fiberglass. For these reasons, it is difficult to describe an 8-hour average exposure level. Exposure levels are, therefore, often reported as short term concentration measurements associated with installation of a specific product rather than as 8-hour averages (Fowler et al. 1971, Schneider 1982, Head and Wagg 1980).

Information on the number and names of installers who handle fiberglass insulation products is not currently available.

a. Installation and Removal Processes/Potential Exposure Points

(1) Process Description and Automation

The activity of insulation workers is highly variable and depends on the type of product being installed and the type of job site at which the work is being done. In general, the installation of insulation products, with the exception of blowing wool, involves three basic steps: fabrication, application, and finishing. Fabrication involves the cutting and/or shaping of the insulation product to the required dimensions. This is usually done in an open and relatively well ventilated area (Fowler et al. 1971). The fabricated product is then applied to the area to be insulated and secured in place with adhesive tape, glue, staples, or similar materials. The installation is finished by covering the application area with paneling or wallboard. Blowing wool is added to the blowing machine at a location remote from the area to be insulated and is conveyed pneumatically to the area to be insulated. Installation procedures for specific products are described below. Insulation contractors have indicated that installation procedures have not changed significantly since the 1970's (ICAA 1986, Fisher 1986).

Installation of Duct and Pipe Insulation. Pipes and ventilation ducts can be insulated with several types of insulation products, depending on the size and shape of the duct or pipe. Pipe covering, consisting of two molded half cylinders, can be installed on round ducts. The two pieces are cut to length, or supplied pre-cut, and taped together around the duct. Larger ducts and pipes, or ducts which are not round, can be insulated using blanket or wrap-around insulation. Blanket insulation is a flexible product which is wrapped around the duct in a spiral fashion; wrap-around insulation is an aluminum covered fiberglass sheet which is cut to length and wrapped around a section of the duct. Both types of insulation can be secured with tape, glue, or similar material (Esmen et al. 1982).

Installation of Building Insulation. Flexible low density fiberglass batts are installed in the floors, walls, and rafters of residential and commercial buildings as thermal or acoustical insulation. The batts are cut to the proper length, on-site or at a remote location such as a manufacturing facility, and stapled into the areas to be insulated; large flat areas, such as ceilings, may be insulated with higher density rigid boards which are installed using a similar procedure (Fisher 1986, Esmen et al. 1982, ICAA 1986).

Fabrication and Installation of Fiberglass Ducts. Fiberglass ducts for use in ventilation systems are fabricated from rigid fiberglass boards. The preformed boards are bent into shape and stapled together by a fabrication worker. The ducts are then installed by insulation and sheet metal workers (Esmen et al. 1982).

Installation of Blown Insulation. In installation of blown insulation, the blowing machine operator (feeder) opens bags of blowing wool and empties them into the blowing machine, usually located inside a truck outside the building to be insulated. The roofer (or blower) prepares the area to be insulated, and the blower directs the insulation from the blowing hose to the desired location. Installation of blowing wool is usually a two or three person operation, the roofer not always participating in the installation (Fisher 1986, Esmen et al. 1982, ICAA 1986).

Installation of Industrial Equipment Insulation. In industrial installations, thermal or acoustical insulation may be fabricated on site for plant mechanical equipment. Worker activity is similar to that of duct insulation, except that the fabrication step may be more complex as irregular shapes may be involved (Esmen et al. 1982).

(2) Engineering Controls and Protective Equipment

Ventilation. Several studies have identified work area ventilation as a critical parameter in minimizing worker exposure (Esmen et al. 1982, Schneider 1982). Ventilation in insulation work areas is generally natural because the application of exhaust systems is not possible in most job areas (Head and Wagg 1980, Fisher 1986). The level of ventilation is, therefore, highly variable between jobsites and between areas at a particular job site. The quality of ventilation is dependent on many factors, the most important of which is whether the work area is open or enclosed.

According to Esmen et al. (1982), application areas in industrial facilities, such as those studied by Fowler et al. (1971), and attic areas, where blowing wool is installed, are generally not well ventilated.

Exposure levels for residential and commercial building application areas are reported by Esmen et al. (1982). Most of the installation areas studied were found to be well ventilated because doors and windows were left open during installation. Insulation contractors indicate that the large majority of insulation operations at residential and commercial jobsites are well ventilated (ICAA 1986, Fisher 1986).

Schneider (1982) separated exposure data from one European study into well-ventilated and poorly-ventilated categories based on the estimation of the ventilation parameter NH, where N is the estimated number of air changes per hour in the application area and H is the ceiling height. The fiber concentrations were determined by phase contrast microscopy. The data are presented graphically in Figures 11 and 12. The geometric mean airborne fiber concentrations are generally much lower for the well-ventilated areas, 0.01-0.1 fibers/cc compared to 0.04-5.0 fibers/cc for the poorly ventilated areas. The percent of respirable airborne fibers cover about the same range independent of the level of ventilation (50-90 percent); however, the distribution of respirable fibers in well-ventilated areas is broader. The author acknowledges that differences in fiber generation rates between fiberglass products may account for some of the variation in concentrations, but maintains that the level of ventilation (value of NH) is important in determining fiber concentrations and the fiber diameter distribution.

Fowler et al. (1971) noted that the maximum exposure levels were found in confined, poorly ventilated areas, or areas where housekeeping activities had generated high dust levels. The authors expect these high exposure and poorly ventilated work areas to be relatively rare because housekeeping is commonly done only at the end of each shift and fabrication operations, which generate relatively high fiber concentrations, are usually performed in open areas.

Protective Equipment. Worker protection in the installation of fiberglass insulation is primarily focused on dermal rather than respiratory exposure because fiberglass dust is a skin irritant. Long sleeves and gloves are sometimes specified to minimize dermal exposure; workers who have long experience with fiberglass insulation are less suspectible to irritation and may forego extensive protection.

Heat stress is also a significant problem for insulation workers. Insulation work areas are ventilated as much as possible by opening doors and windows to protect against heat stress as much as against respiratory

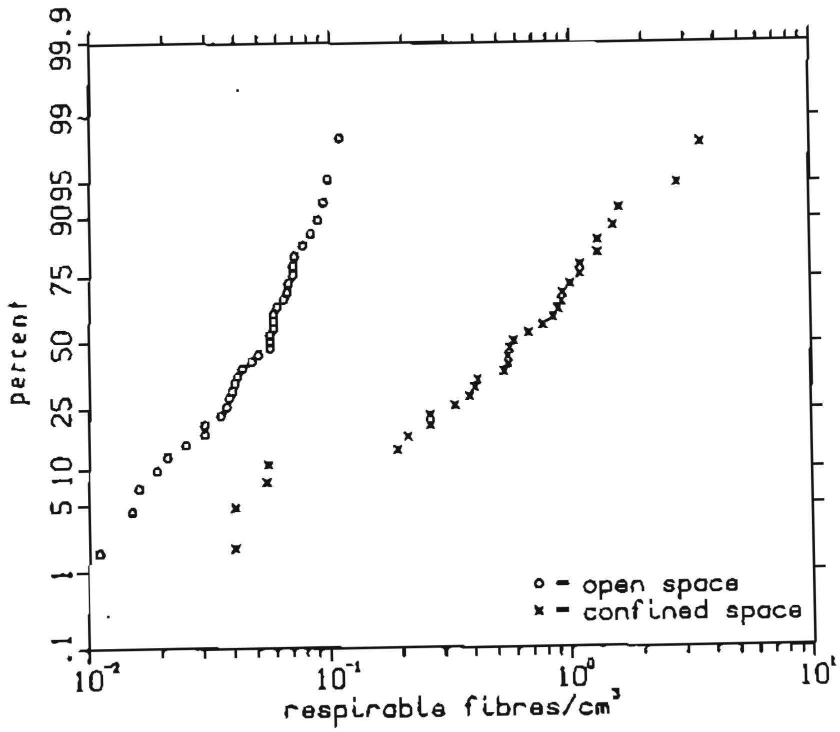

Figure 11. Cumulative plot of concentrations of respirable fibers longer than 5 µm, determined by optical microscopy for measurements in confined, non-ventilated places and in open, well-ventilated spaces. (Source: Schneider 1982.)

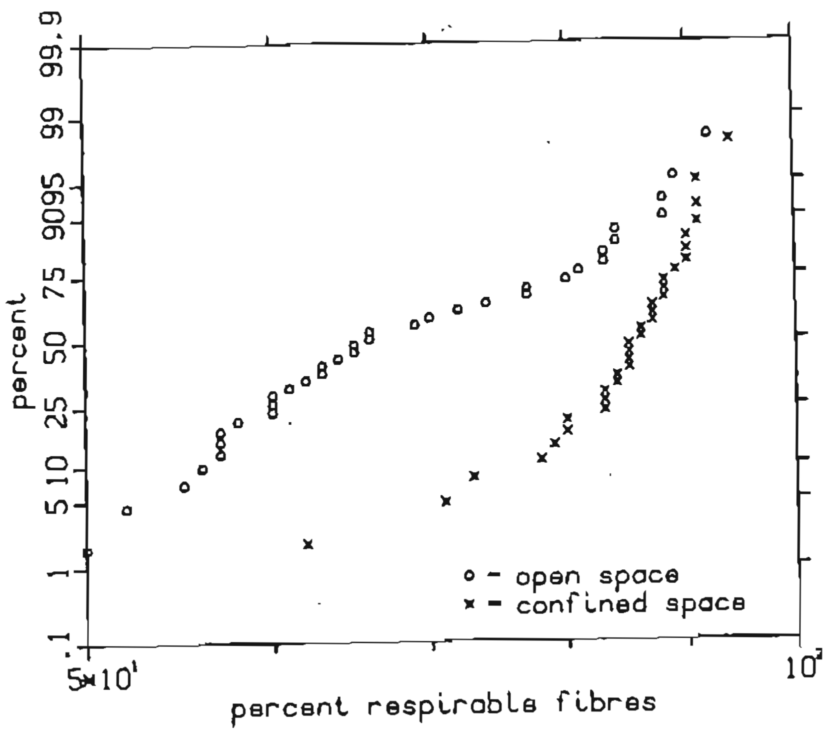

Figure 12. Cumulative plot of the percentage of respirable fibers longer than 5 μm, determined by optical microscopy corresponding to the same groups of measurements shown in Figure 11. (Source: Schneider 1982.)

exposure. Respiratory exposure may not be perceived as a significant problem by workers or contractors (ICAA 1986, Fisher 1986).

Only one of the previously cited exposure studies (Apol et al. 1980) references the use of respirators during parts of the installation process. Insulation contractors generally provide filter masks to their insulation workers; but the use of these masks is not always enforced, and workers generally prefer not to use such devices because they are uncomfortable to wear. Workers would be more inclined to wear masks when installing attic insulation or blowing wool since this is a particularly dusty operation (Apol et al. 1980, Fisher 1986, ICAA 1986). Esmen et al. (1982) report that the blowing wool workers studied did not wear the respirators issued to them. This study found very high total dust levels in blowing wool application areas.

b. Extent of Potential Exposure

(1) Number of Persons Exposed/Duration of Exposure

In general, 2-3 workers are required for the installation of blowing wool; one or two workers are sufficient for the installation of other types of insulation materials.

As previously discussed, insulation workers are not continuously exposed to airborne fibers throughout the workday, but spend a significant amount of time in transit between jobsites, between work areas on site, and on work breaks (breaks are frequent to protect against heat stress). One contractor estimated that an insulation worker actually installs insulation only 5 hours of a typical 8 hour day (Fisher 1986). Esmen et al. (1982) estimated that between 40 percent and 80 percent of the work day is spent in transit. Because the exposure duration for insulation workers is significantly less than a full 8 hour day, the 8 hour time-weighted average exposure will be only a fraction of the short term exposure measured during actual installation operations (Fowler et al. 1971).

Both Fowler et al. (1971) and Schneider (1982) discuss secondary exposure where workers who are not technically classified as insulation workers are exposed to fiberglass. Fowler et al. (1971) reports concentration data taken at locations 10 to 20 feet from the insulation workers; concentrations were approximately an order of magnitude lower than concentrations measured at the installation area. Schneider (1982) reports the results of a Danish study (Petersen and Venstrup-Neilsen 1981) which surveyed the exposure pattern of workers in the Danish Carpenters and Joiners Union. The data reproduced in Table 31 indicate that approximately 20 percent of all workers spent more than three days each month working with man-made mineral fibers. These studies indicate that secondary exposure, although much lower in extent and duration than direct exposure, is nevertheless significant.

(2) <u>Exposure Levels/Respirability of Airborne Fibers</u>

Exposure data for installation of various types of insulation materials have been reported by researchers in the U.S. (Esmen et al. 1982, Apol et al. 1980, Fowler et al. 1971), Scandinavia (Schneider 1979), Great Britain (Head and Wagg 1980), and Germany (Riediger 1982). Schneider (1979) reports exposure data for removal of mineral wool insulation from an existing structure. These studies generally conclude that, with the exceptions of installation of attic insulation (blowing wool, fiberglass blanket), insulation removal, and other applications conducted in enclosed areas, exposure levels during installation are the same or lower than during manufacture of the insulation product. As previously discussed, exposure levels are highly dependent on the quality of ventilation in the work area.

Table 31. Percentage Distribution of Hours Per Month Spent on Work with Man-Made Mineral Fibers During the Period Spring 1978-Spring 1979

Job	Number of Hours					Number of Persons Surveyed
	0	1-8	9-16	17-24	25-190	
Cabinet Makers	61.6	17.9	6.4	3.7	10.4	297
Pattern Makers	77.0	0.0	9.0	5.0	9.0	22
Joiners	17.7	36.0	19.9	5.9	20.4	186
Carpenters	6.4	35.8	26.7	11.4	19.6	1,232
Glaziers*	90.0	5.0	0.0	5.0	0.0	22
Others	70.1	7.5	1.5	1.5	19.4	67
All	20.8	31.1	21.2	9.1	17.9	1,826

* Glass workers.

Source: Schneider 1982.

Exposure data summarized in this section represent short-term exposures associated with a specific job function and are not 8-hour time-weighted averages (TWA) unless specified as such. The 8-hour TWA exposure levels are generally significantly lower than short-term exposure levels because insulation workers spend a significant portion of each workday in an environment free of airborne glass fibers (Esmen et al. 1982). Exposure data for installation of insulation products are discussed below.

Blowing Wool. Exposure data for total and respirable airborne fibers from fiberglass blowing wool installation operations are summarized in Table 32. (Exposure levels for blown mineral wool are discussed in Chapter VIII.) Fiber concentrations for blowing wool installation tend to be higher than concentrations for installation of other fiberglass insulation products because of the method of application and the generally lower level of ventilation in the installation areas (Esmen et al. 1982). As previously discussed, workers may alternate jobs in blowing wool installation. A composite 8-hour TWA exposure was calculated by Esmen et al. (1982) for the blowing wool workers based on the amount of time spent in each job area. As shown in Table 32, the composite exposure level is much less than half the peak exposure level indicated for the blower. The blower operator is exposed to the highest airborne fiber concentrations (1.8 fibers/cc average, 0.67-4.8 fibers/cc range). The feeder operator and roofer are exposed to much lower levels because they are generally working in better ventilated areas than the blower operator. Overall, 60 percent of the airborne fibers were respirable. Forty-four percent of the fibers to which the blower operator is exposed are respirable, and 91-92 percent of the fibers to which the feeder and roofer operators are exposed are respirable.

Table 32. Respirable Fiber Concentrations --
Residential Fiberglass Blowing Wool Installation

Job Classification	Number of Samples	Arithmetic Average (fibers/cc)	Range (fibers/cc)	Average Respirable Fraction
Roofer	6	0.31	0.073-0.929	0.91
Blower	18	1.8	0.67-4.8	0.44
Feeder	18	0.70	0.059-1.48	0.92
Composite Roofer, Blower, and Feeder Tasks (Calculated 8-hour TWA)	18	0.70	0.42-1.2	0.60

Source: Esmen et al. 1982.

Insulation of Pipes and Ducts. Airborne concentrations of total and respirable fibers from several studies of the installation of pipe and dust insulation are summarized in Table 33. Exposure levels were found to be generally very low for installation in commercial facilities (less than 0.4 fibers/cc and averaging about 0.05-0.06 fibers/cc), and 70-90 percent of the fibers were respirable (Esmen et al. 1982).

Breathing zone concentration measurements for installation of pipe insulation in industrial facilities show much higher exposure levels (0.66-1.17 fibers/cc average) and a lower fraction of respirable fibers (Fowler et al. 1971). Sampling and analysis techniques used by Fowler et al. (1971) are similar to those described by Esmen et al. (1979). Personal samples were taken by flow rates between 2 and 3 liters per minute, and area samples from 25 to 30 liters per minute. Sampling periods ranged from 20 to 60 minutes. Application of wrap-around insulation generates greater levels of airborne fibers than does application of pipe insulation; 0.51-2.34 fibers/cc for wrap-around insulation versus 0.48-0.83 fibers/cc for pipe insulation. Esmen et al. (1982) indicate that the industrial application areas tend to be less well ventilated than commercial application areas, which may account for the large difference in exposure levels between the studies.

Installation of Fiberglass Ducts. Esmen et al. (1982) measured exposure levels during the fabrication and installation of fiberglass ducts as summarized in Table 34. Each worker worked an 8-hour shift at a single job. Measured fiber concentrations for each of the job classifications were less than 0.20 fibers/cc, with average exposure levels near 0.02 fibers/cc for all operations. An average of 65 to 87 percent of the measured airborne fibers were respirable. The duct installer was exposed to the highest peak concentration (0.2 fibers/cc) and the highest respirable fraction (87 percent).

Table 33. Respirable Fiber Concentrations -- Fiberglass Pipe/Duct Insulation

Insulation Product/ Application Area	Number of Samples	Arithmetic Average (fibers/cc)	Range (fibers/cc)	Average Respirable Fraction	Reference
Pipe Covering -- Commercial	31	0.06	0.0074-0.38	0.82	Esmen et al. 1982.
Blanket Insulation -- Commercial	8	0.05	0.025-0.14	0.71	Esmen et al. 1982.
Wrap-Around -- Commercial	12	0.06	0.030-0.15	0.77	Esmen et al. 1982.
Wrap-Around -- Industrial (Breathing Zone)	9	1.17	0.51-2.34	NR (Mean Diameter 3.8 um)	Fowler et al. 1971.
Wrap Around -- Industrial (Work Area)	5	0.05	0.02-0.09	NR (Mean Diameter 4.3 um)	Fowler et al. 1971.
Pipe Insulation -- Industrial (Breathing Zone)	3	0.66	0.48-0.83	NR (Mean Diameter 3.5 um)	Fowler et al. 1971.
Pipe Insulation -- Industrial (Work Area)	6	0.06	0.02-0.09	NR (Mean Diameter 2.8 um)	Fowler et al. 1971.

NR = Not Reported.

Source: Esmen et al. 1982.

Table 34. Respirable Fiber Concentrations -- Industrial Fiberglass Duct Fabrication and Installation

Job Classification	Number of Samples	Average (fibers/cc)	Range (fibers/cc)	Average Respirable Fraction
Duct Fabricator	4	0.02 (8 hr. TWA)	0.0059-0.046	0.66
Sheetmetal Worker	8	0.02 (8 hr. TWA)	0.0050-0.054	0.65
Duct Installer	5	0.01 (8 hr. TWA)	0.0063-0.20	0.87

Source: Esmen et al. 1982.

Installation of Residential Building Insulation. Airborne concentrations of the total and respirable fibers from the installation of residential building insulation are summarized in Table 35. The maximum measured concentration was 1.8 fibers/cc for installation of fiberglass blanket in an attic; average concentrations range from 0.10 to 1.02 fibers/cc. The highest measurements are for applications in enclosed areas and are attributed to poor ventilation (Head and Wagg 1980, Schneider 1979). Between 80 and 90 percent of the measured fibers were respirable. Apol et al. (1980) reported exposure levels from the installation of fiberglass blanket and pipe and duct wrap-around insulation in residential crawl spaces as time-weighted averages. Only three of thirteen samples contained measurable quantities of fibers; average concentration for the three samples was 0.022 fibers/cc. Workers were exposed to high levels of total dust in the work areas, but very low levels of respirable fibers.

Miscellaneous Installation of Insulation Products. Esmen et al. (1982) reported exposure measurements for installation of acoustic ceiling tile. Exposure levels are very low in these operations (0-0.0056 fibers/cc), and the fraction of respirable fibers is lower than those found for installation of residential insulation (approximately 55 percent). Fowler et al. (1971) reported exposure data for insulation of walls, plenums, and mechanical equipment in industrial facilities. Although average exposure levels are high (4.0 fibers/cc for wall insulation and 1.6 fibers/cc for industrial equipment insulation), less than half of the measured fibers were respirable. The data are summarized in Table 36.

c. Conclusion

Average airborne fiber concentrations from installation of standard insulation products have generally been found to range from 0.02-1.2

Table 35. Respirable Fiber Concentrations -- Residential Building Insulation

Installation Product/ Application Area	Number of Samples	Arithmetic Average (fibers/cc)	Range (fibers/cc)	Average Respirable Fraction	Reference
Fiberglass Blanket -- Residential Attic Onsite	5	0.38	0.30-0.54	0.80	Head and Wagg 1980.
	7	1.02	0.24-1.76	0.80	Head and Wagg 1980.
Fiberglass Blanket -- Residential Wall and Attic Onsite	31	0.13	0.013-0.41	0.91	Esmen et al. 1982.
	31 (Composite)	0.12	0.089-0.22	0.92	Esmen et al. 1982.
Composite of Blanket and Duct/Pipe Wrap-Around -- Residential Crawl Spaces	3	0.022 (8 hr. TWA)	0.021-0.025	NR[a]	Apol et al. 1980.
Fiberglass Blanket -- Indoor	NR	NR	0.1-0.9 (>1 um) 0.1-0.9 (<1 um)	NR (Mean Diameter 0.4 um)	Riediger 1982.
Fiberglass Blanket -- Outdoor	NR	1.1	--	NR (Mean Diameter 1.9 um)	Riediger 1982.

NR = Not Reported.

[a] Ten of 13 samples were below the limit of detection. Reported concentration is respirable fibers only; however, most airborne fibers are larger than 3.5 um.

Source: Head and Wagg 1980, Schneider 1979.

Table 36. Respirable Fiber Concentrations -- Miscellaneous Residential/Commercial/Industrial Installation

Installation Product/ Application Area	Number of Samples	Arithmetic Average (fibers/cc)	Range (fibers/cc)	Average Respirable Fraction	Reference
Acoustic Ceiling Tile -- Commercial	12	0.0028	0.0-0.0056	0.55	Esmen et al. 1982.
Fiberglass Board -- Industrial Wall Insulation					
Breathing Zone	4	4.01	0.53-8.08	NR (Mean Diameter 5.8 um)	Fowler et al. 1971.
Work Area	5	0.20	0.01-0.47	NR (Mean Diameter 4.8 um)	Fowler et al. 1971.
Fiberglass Board -- Industrial Equipment					
Breathing Zone	1	1.57	-	NR (Mean Diameter 3.5 um)	Fowler et al. 1971.
Work Area	1	0.20	-	NR (Mean Diameter 3.4 um)	Fowler et al. 1971.

NR = Not Reported.

Source: Fowler et al. 1971, Esmen et al. 1982.

fibers/cc. The installation of insulation in relatively enclosed and/or poorly ventilated areas, such as residential attics and industrial jobsites, resulted in short term fiber concentrations on the order of 1 to 2 fiber/cc and as high as 4 to 5 fibers/cc. From 50 to 90 percent of the measured fibers have been found to be respirable. Because fiberglass insulation workers are not continuously exposed to a fiber containing environment, 8-hour TWA exposure levels may be less than half the measured short term concentrations.

Ventilation is an important parameter in limiting airborne fiber concentrations during installation of insulation materials, and a correlation has been found between the quality of ventilation and exposure levels. Natural ventilation must be relied upon at installation sites because application of exhaust systems is impractical. Since workers in many jobsites are subject to heat stress, they have an incentive to maximize work area ventilation by keeping doors and/or windows open. Residential and commercial jobsites are generally easier to ventilate than industrial jobsites. Residential and commercial attics and crawl spaces are also difficult to ventilate.

Respirators or dust masks are generally made available to insulation workers, but they are not always required and not always used. Respirators may be more heavily used by workers in areas that have high concentrations of total dust (such as residential attics) because of general irritation and nuisance factors. Fiberglass dust may not be perceived as a hazard by workers or contractors, who are generally more concerned about dermal exposure to fiberglass. In most cases, short-term exposure levels are low, and the duration of exposure is considerably less than eight hours. Therefore, 8-hour TWA are very low.

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VIII. MINERAL FIBER

Mineral wool is a generic term that means any fibrous glassy substance made from minerals (e.g., natural rock) or mineral products (e.g., slag or glass). In this chapter, mineral wool includes only those fibers made from natural rock (rock wool) or from slag (slag wool); fibrous glass has been discussed in a previous chapter (see Chapter VII). Most of the mineral wool produced in the United States is from blast furnace slag; only a small amount is produced from natural rock (Fowler 1980, Bethlehem Mines 1986).

Rock wool and slag wool fibers are used principally for commercial, industrial, and residential insulation -- commonly in the form of a loose wool called "blowing" or "pouring" wool, "batts", and "blankets". Mineral wool fibers are also used in acoustical ceiling tiles and panels, roof insulation, and reinforced materials. Mineral wool is a desirable material because of its excellent insulating ability and its noncombustibility. The majority of the fiber producers today produce blowing/pouring wool (Fiberfine 1986, L.C. Cassidy & Son 1986a). The production of mineral wool blankets is phasing out since blankets made from fiberglass are more economical (Fiberfine 1986). Few companies are still producing batts. Most mineral wool fibers range from 6-9 µm in nominal diameter.

A. Fiber Production

1. Fiber Producers

Based on a recent market study conducted by ICF (1986), there are nine manufacturers of mineral wool fibers operating a total of 18 plants (see Table 1). We contacted seven of the nine manufacturers concerning the production of mineral wool. U.S.G. Co. is considered the largest producer of mineral wool fiber followed by Rockwool Industries. Bethlehem Mines is phasing out its mineral wool production.

Table 1. Manufacturers of Mineral Wool

Company	Plant Location	Number of Employees at Plant Site
American Rock Wool, Inc.	Nollanville, TX	100
	Spring Hope, NC	115
Bethlehem Mines Corp.[a]	Bethlehem, PA	69
L.C. Cassidy & Son Inc.	Indianapolis, IN	50
Fiberfine	Memphis, TN	29
Forty-Eight Insulation, Inc.	Aurora, IL	N/A
Jim Walter Corp.		
Coke, Iron & Chemical Division	Birmingham, AL	90[b]
Celotex (subsidiary)	Largo, IN	140
Celotex (subsidiary)	Harding, PA	100[c]
Rockwool Industries, Inc.	Alexandria, IN	150
	Belton, TX	250
U.S.G. Co.[d]	Birmingham, AL	100
	Corsicana, TX	N/A
	Gypsum, OH	N/A
	Red Wing, MN	N/A
	Tacoma, WA	N/A
	Wabash, IW	N/A
United States Mineral Products Co.	Stanhope, NJ	100

[a] Company is phasing out its mineral wool production.

[b] Eighty-two employees involved in production of mineral wool.

[c] Forty-two employees involved in production of mineral wool, and 54 employees involved in secondary processing of mineral wool (i.e., fabrication of ceiling tiles and boards).

Table 1 (Continued)

[d] Formerly called U.S. Gypsum Co.

N/A means not available.

Sources: Dun's Market Identifier 1986, USDOC 1985, Industry contacts 1986.

2. Fiber Production Process/Potential Exposure Points

a. Process Description and Automation

According to industry sources, the basic process by which mineral wool is made today is similar to that used in the 1950s (L.C. Cassidy & Son 1986a; Forty-Eight Insulation 1986; Fiberfine 1986; U.S.G. 1986; United States Mineral Products 1986; Esmen 1986). These sources also provided the following information on the fiber production process. The raw material (e.g., 30 percent from copper slag, 70 percent from blast furnace slag in steel production, and/or natural volcanic rock) is first loaded into a cupola in alternating layers with batches of coke and small amounts of other raw materials used to give the fibers special characteristics of ductility or size. The coke is burned, generating high temperatures and melting the slag (see Figure 1 for a schematic of the slag wool cupola). The molten stream of slag flows from a hole in the bottom of the cupola and falls onto a centrifugal spinner (spinning in the vertical plane). The slag flows to the edge of the spinner and is partially fiberized (see Figure 2). The partially fiberized slag or rock is then further attenuated by the interception with an annular stream of steam or air. When the stream of steam or air intercepts the falling stream of slag, it breaks the molten slag into many small globules which then "tail out", producing fibers with a semi-spherical head. These heads then break off as the material is cooled, and thus produce fibers and "shots" (the cooled heads). These shots are undesirable* and are separated from the fibers as shown in Figure 1. Most fiber manufacturers use this process with possible variation in the spinning step. Producers either use

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* The shots do not provide insulation properties but add weight to the product. These shots are disposed in a landfill.

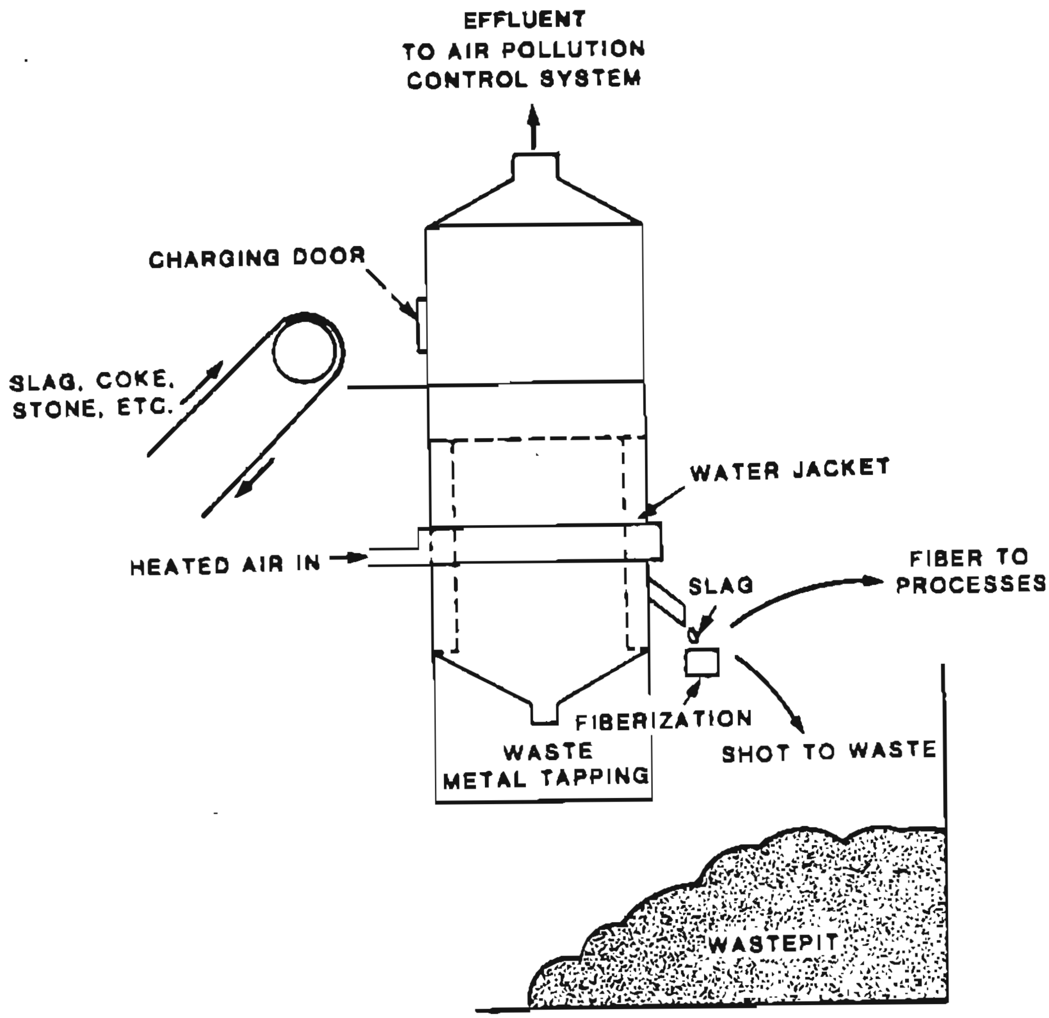

Figure 1. Slag wool cupola.

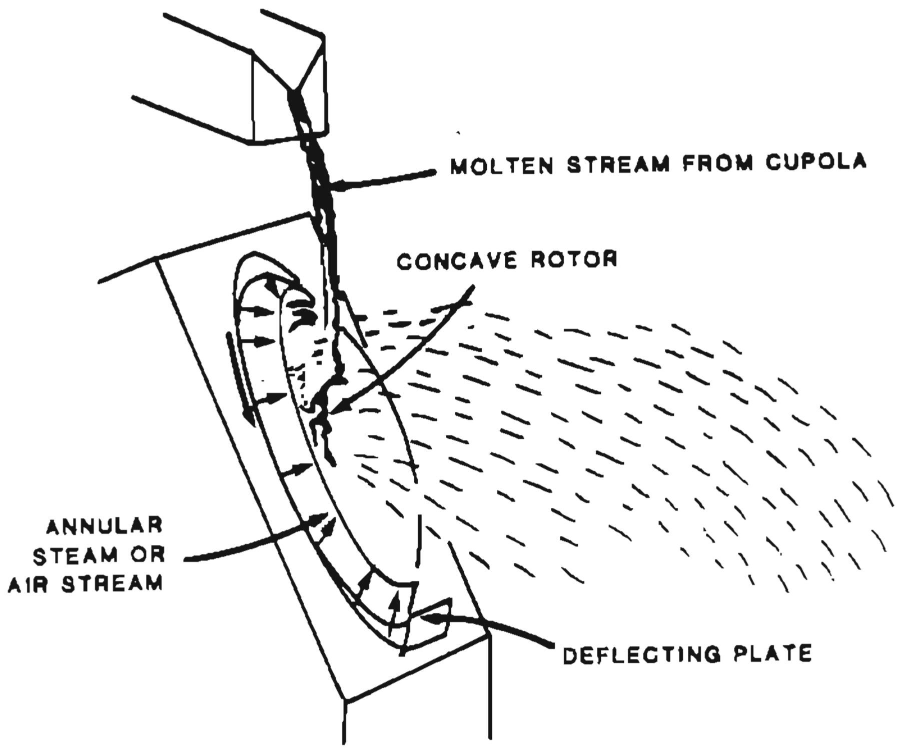

Figure 2. Mineral wool fiberization process.

the concave rotor/centrifugal spinner for the spinning process or the 4-wheels vertical spinning process. This choice of spinning technique does not change the characteristics of the fiber or its size (Forty-Eight Insulation 1986). The spinning and fiberization processes are enclosed according to some manufacturers (U.S. Mineral Products 1986, L.C. Cassidy & Son 1986b) to reduce exposures to lead fumes, heat, and noise.

As the fiber is formed, it may be further treated to increase its utility for one or more of its intended uses. In general, these treatments are applied immediately following the spinning process by the atomization of liquids (aerosol mist) that are "sprayed" onto the newly formed fibers. These treatments are performed in the blow chamber. In almost all cases, a de-dusting oil (1-2 percent) will be applied in the same way within the blow chamber to reduce the "dustiness" (tendency to become airborne) of the bulk products. A "binder" (usually a phenol formaldehyde resin) may be added immediately following or in place of the oil treatment.

Up to this point, the process by which the fiber is formed is the same regardless of the types of products being produced (i.e., loose wool or batts). Since a fiber producer often has two production lines, one for producing loose wool and the other for producing batts, two model lines are presented, one for each type of product* (see Figure 3). Each production line has its own cupola.

(1) <u>Wool Line</u>

The wool line is for the production of blowing wool or "pouring wool." Following the attenuation step, the fiber is conveyed to the blow chamber and a de-dusting oil is added. The fibers are collected on a

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* Fiber manufacturers often use both lines to produce loose wool.

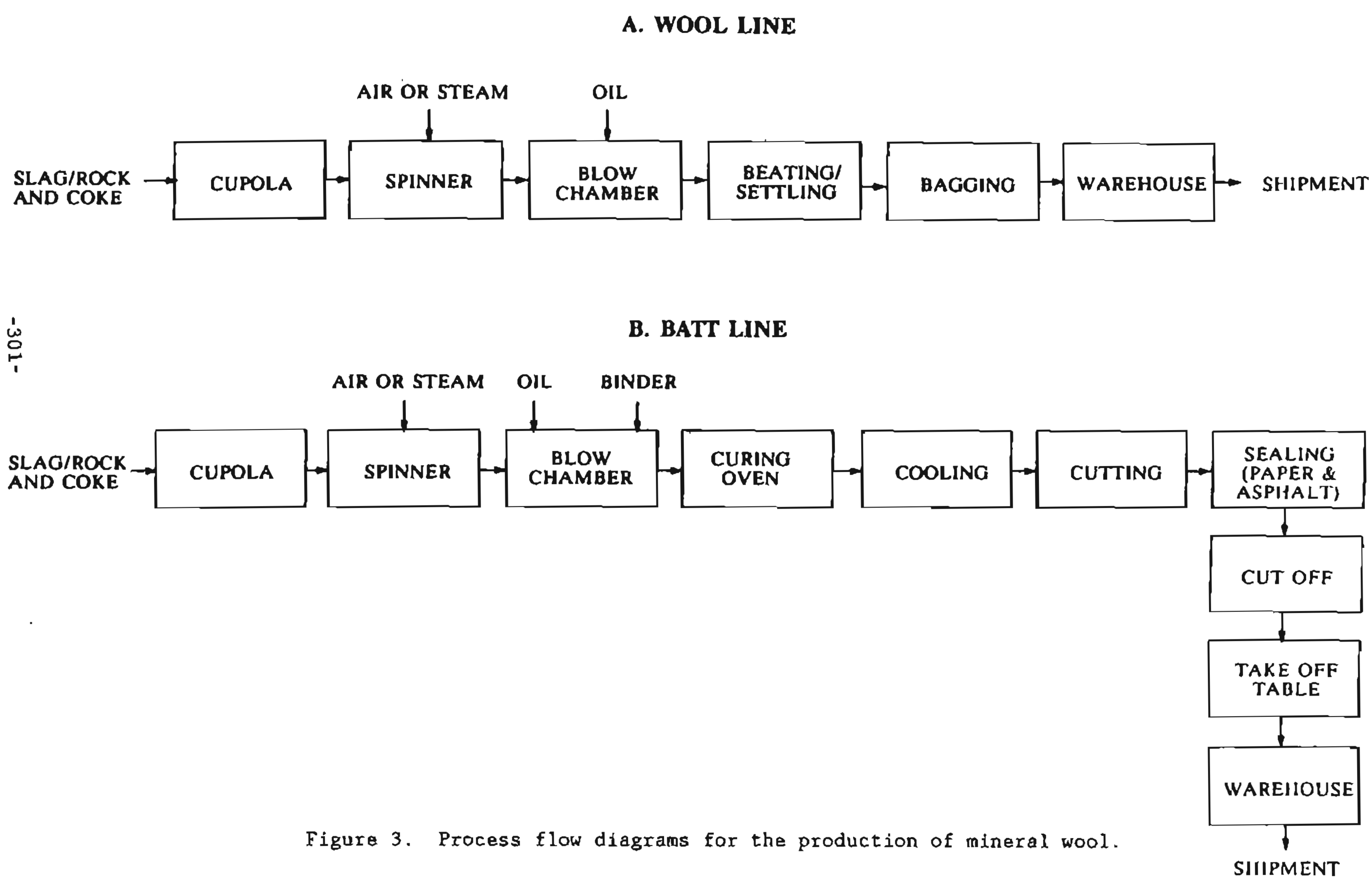

Figure 3. Process flow diagrams for the production of mineral wool.

moving chain screen, conveyed to a transversely moving conveyor belt where they are broken into clumps by a beater paddle, and then transported to an air lift. The fiber clumps are airlifted to the top of the packaging column of the bagging machine. At the bagging machine, the bagger loads the Kraft bag onto the machine and controls the bagging machine to weigh the wool. The machine fills bags with wool by hydraulic injection. The bagger then tapes the product label onto the bag, and the bags are taken to the warehouse for temporary storage or are loaded onto trucks for shipment (see Figure 3A). The production line is automated, thus only the work at the cupola area and the packaging area are labor intensive (L.C. Cassidy & Son 1986b, Bethlehem Mines 1986). Only the fiber forming process (i.e., spinning and fiberization) and the treatment process (addition of oil or binder) are enclosed (U.S. Mineral Products 1986, L.C. Cassidy & Son 1986b).

(2) Batt Line

On the batt line, after the fiberization step, the fibers are pulled into the blow chamber for the addition of de-dusting oil and binder. The fibers are formed into a fibrous mat on a metal mesh conveyor belt in the blow chamber. The speed of the belt is set to give the desired thickness of the fibrous mat. The mat is compressed to the required density and then passed through a "curing oven" where the binder is baked and cured.
A cooling section with down-draft air follows. The continuous mat is then slit longitudinally to the desired size by circular saws. Following the slitting, the cut sections of the mat are usually covered with either paper (common brown Kraft paper) or aluminum foil-backed paper. Asphalt treated paper is also used to serve as a vapor barrier. The paper-wrapped lengths of wool are then cut again transversely by circular saws. The cut batts are manually moved onto a "take-off" table, where they are stacked into

compression bagging machines by the take-off table workers. The cut batts are then bagged by a hydraulic compression bagging machine, taped closed, and moved to the warehouse for storage or shipment. The packaging steps are not enclosed. See Figure 3B for a process flow diagram of a model batt line.

b. Engineering Controls and Protective Equipment

All mineral wool fiber manufacturers contacted have some engineering controls in their plants. All mineral wool production plants have general ventilation systems in the main part of the plant (Bethlehem Mines 1986; L.C. Cassidy & Son 1986b; Fiberfine 1986; United States Mineral Products 1986; Fowler 1977, 1978a, 1978b, 1980). Local ventilation systems are usually located at the bagging station and sometimes at the cupola area (U.S. Mineral Products 1986, Fowler 1978b). Some plants pass their cupola area ventilation exhaust to a wet scrubber prior to release to the atmosphere (U.S. Mineral Products 1986, Fowler 1978b). The wet scrubber is an emission control device used here to reduce exposures to smoke, metal fumes, hydrogen sulfide, carbon monoxide, silica, and fly-ash (generated during burning of the raw materials) in the cupola area. There are no fibers at the cupola; however, it is possible that airborne fibers from other production steps could be blown into the cupola area. Any fibers would be removed by the wet scrubber. The phenolic vapors and gases from the curing oven are also vented to the scrubber. Dust collection systems such as baghouses are also used to meet air pollution control requirements (U.S. Mineral Products 1986, L.C. Cassidy & Son 1986b, Bethlehem Mines 1986). Other engineering controls are available at the facilities; however, these controls are not intended for reduction of airborne fibers.

Personal protective equipment such as disposable dust masks and/or respirators are available at all plants (Bethlehem Mines 1986; L.C. Cassidy &

Son 1986b; Fiberfine 1986; United States Mineral Products 1986; Fowler 1977, 1978a, 1978b, 1980); however, usage of respirators is optional. Plant managers stated that the baggers and the take-off table workers use respirators frequently since they are working in the dustiest areas of the production line (U.S. Mineral Products 1986, L.C. Cassidy & Son 1986b, Fiberfine 1986).

3. Extent of Potential Exposure

Sources of fiber emissions to the general workplace air during wool production are the air lift operations, bagging, and equipment breakdowns. According to Fowler (1980), equipment at mineral wool production plants are usually old; therefore, equipment failures occur frequently. Breakdowns contribute to fiber exposure because the wool fibers continue to be produced at the cupola, thereby producing waste fibers which pile up on the floor (Fowler 1980). Maintenance personnel are exposed during cleanup and equipment repair. For the batt process, equipment breakdowns are also a source for fiber emissions. Breakdowns occur more frequently on batt lines than on wool lines (Fowler 1980). Releases of fibers occur largely from the packaging operations.

a. Number of Persons Exposed

The total number of employees for each mineral wool plant is shown in Table 1. The total number of plant employees ranges from 29 to 250 workers and is comprised of labor for:

- Production;
- Maintenance;
- Warehouse; and
- Supervision and clerical.

The production and maintenance workers have the highest potential exposure to mineral wool fibers. These two job categories represent approximately 70-80 percent of the total plant employment based on industry contacts (L.C. Cassidy & Son 1986b, Bethlehem Mines 1986, Fowler 1980). Also, it should be noted that the number of employees shown in Table 1 represents the total number of workers on all shifts. Mineral wool plants usually run three shifts per day and five to seven days per week (L.C. Cassidy & Son 1986b, Fiberfine 1986). Table 2 summarizes the expected number of workers for each model production line by job category. The number of workers on a wool line ranges from 6 to 9 per shift, while the number of workers on a batt line ranges from 10 to 13 per shift. In addition, there are other workers potentially exposed to mineral wool at the plant such as the maintenance crew, the quality control person, and the utility cleanup workers for the entire plant.

The job responsibilities of each job category is similar for both the wool line and the batt line. The batt line has an additional job category for the take-off table workers. These workers manually remove the completed batts from the machine and place them in compression packers for bagging and shipping. The take-off table workers apparently have the greatest potential exposure to airborne fibers since their work involves direct contact with mineral wool. The job responsibilities and extent of worker exposure for each job category are:

<u>Cupola Charger</u> -- loads raw materials into the charging door of the cupola. Exposures are most likely to be to metal fumes and smoke from combustion products rather than to fibers.

<u>Cupola Operator</u> -- maintains a constant and adequate flow of molten slag to the spinner, where the fiber is produced. Exposure is likely to be to metal fumes, smoke, and fibers.

<u>Bagger</u> -- fits the bags onto the bagging machine, and removes the filled bags. Exposure to fiber is very high since mineral wool fibers can easily escape to the surrounding air.

Table 2. Number of Workers Potentially Exposed to Mineral Wool Fibers During Production

Wool Line		Batt Line	
Job Description	Number of Workers	Job Description	Number of Workers
Cupola Charger	1-2	Cupola Charger	1-2
Cupola Operator	1	Cupola Operator	1
Bagger	1-2	Batt Machine Operator	1-2
Taper	1	Take-Off Table Workers	2-3
Loader (Forklift Operator)	1	Bagger	1
Wool Line Cleanup and Relief	1-2	Taper	1
		Loader (Forklift Operator)	1
		Batt Line Cleanup and Relief	2
Total Workers Per Wool Line	6-9	Total Workers Per Batt Line	10-13

Sources: Fiberfine 1986; Fowler 1980, 1978a, 1978b, 1977; L.C. Cassidy & Son 1986b; U.S. Mineral Products 1986; Bethlehem Mines 1986.

Taper -- tapes the packed bags of wool or batts and places them on pallets for removal to the warehouse. Exposure of the taper is less than that of the bagger (however, the taper often relieves the bagger).

Take-Off Table Worker -- removes the batts from the take-off table after they are cut, and packs them into compression packers.

Loader -- operates a forklift and moves the loaded pallets to the warehouse or to shipment (the loader often relieves the bagger or the taper). Exposure to mineral wool is relatively low.

Clean-up -- spends most of the time sweeping, blowing, and removing settled wool fibers and waste batts from the floor area surrounding the wool or batt bagging equipment. Also, responsible for the cleanup of waste "shots" (relieves the taper and bagger). Exposure to mineral wool is high since worker is in direct contact with the waste fibers.

In general, the workers most exposed to airborne fibers on the mineral wool line are the bagger and the clean-up workers. On the batt line, exposure is high for the take-off table workers, the bagger, and the clean-up workers. Exposure varies for the taper and loader throughout the day.

Other workers in the plant that may be exposed to mineral wool fiber are the maintenance workers. The extent of their exposure to fibers varies widely, depending on the frequency of equipment failures. In addition, the quality control person and the fiber testing person (who regularly tests the fiber diameters) may experience relatively intense exposure but for short durations.

b. Duration of Exposure

The duration of fiber exposure for a production worker is normally 8 hours per day and 5 to 7 days per week. When the demand for fiber decreases, mineral wool fiber producers usually compensate for this by shutting down a production line rather than closing down the plant for a short period of time (Fiberfine 1986, L.C. Cassidy & Son 1986b). Exposure varies depending on the job categories. Workers usually interchange jobs within a day (i.e., relieve other workers); therefore, exposure for an individual may be high at a given time and low at other times (Bethlehem Mines 1986; L.C. Cassidy & Son 1986b; Fowler 1980, 1978a, 1978b, 1977).

c. Respirability of Airborne Fibers

Respirable fibers are defined as those with fiber diameters of less than 3.5 µm. Mineral fibers have nominal fiber diameters ranging from 6 to 7 µm (U.S. Mineral Products 1986, L.C. Cassidy & Son 1986b and 1986c); one manufacturer produces a finer diameter product ranging from 3 to 5 µm in diameter (Fiberfine 1986).

According to the Thermal Insulation Manufacturers Association (1983), most products manufactured from mineral wool contain fibers that range from approximately 6 to 9 µm in diameter (nominal diameter). However, the products always contain some fibers with diameters less than 3.5 µm, and a small percentage of fibers with diameters equal to or less than 1.5 µm. Therefore, exposure to respirable mineral wool fibers is likely. According to a study on airborne mineral wool fibers (Esmen 1982), approximately 30 percent of the airborne fibers at the plants surveyed were in the respirable range.

The NIOSH recommended standard for respirable mineral fibers is 3 fibers/cc (fibers longer than 10 microns and less than 3.5 microns in diameter). Mineral wool fibers are classified as nuisance type dust.

d. Summary of Fiber Exposure Data and Past Exposure Studies

An industrywide industrial hygiene survey of mineral wool production plants was performed by NIOSH over the period from 1974 to 1977 (Fowler 1977, 1978a, 1978, 1980). Air samples were taken to evaluate worker exposure to mineral wool fibers. Numerous industry and academic sources (U.S.G. 1986, Forty-Eight Insulation 1986, Bethlehem Mines 1986, Esmen 1986) stated that one can assume exposure to airborne mineral wool fibers today is comparable to that found in 1974-1977 since the production process has remained "exactly" the same.* A study of production trends with respect to mineral wool fiber sizes showed that neither the average fiber diameter nor the percentage of fibers in the respirable range had changed over the years (Konzen 1982). Also, no increase in the percentage of respirable fibers in mineral wool products is anticipated in the future (Konzen 1982). Based on these conclusions, exposure data on past studies are presented here.

Table 3 summarizes the exposure data from the NIOSH industrial hygiene surveys performed at four mineral wool plants (Fowler 1977, 1978a, 1978b; Dement 1975).+ Personal air samples in the breathing zones of workers were taken to determine airborne fiber concentrations. Each worker wore a pair of 37 mm diameter Millipore Type AA (0.8 μm mean pore size) air sampling filters (clipped to his/her shirt collar) and a pump (clipped to his/her belt) during the sampling session which was typically 6 to 7 hours. The sampling period began shortly after the start of a shift and continued until shortly before the end of the shift. The inlet air flow rate ranged from 1.7-2.0 liters/minute, and fiber counting and sizing was done using optical microscopy. Concentrations of airborne fibers at all plants were less than 3 fibers/cc. The nominal fiber diameter of the bulk products averaged around 7 μm; however, median airborne fiber diameters were typically in the range of 1.2 to 2.4 μm. Fifty to 60 percent of the airborne fibers were respirable. Tables

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* The assumption that exposure to airborne mineral wool today is about the same as that found in 1976 to 1977 does not take into account the fact that engineering controls (e.g., local ventilation systems) at the plants today may be slightly better than those used in the past.

\+ Currently, Forty-Eight Insulations' mineral wool plant is temporarily inoperative.

Table 3. Exposure Data on Mineral Wool Plants

Plant	Data Collection Period	Mineral Wool Products	Overall Fiber Concentration (fibers/cc)	Median Airborne Fiber Diameter (um)	Median Fiber Length (um)
Rockwool Industries	September 1976	blowing/pouring wool, batts	0.038-0.234	1.2-2.0	6.7-20
U.S.G. Corporation	October 1976	blowing wool, batts	0.005-2.306[a]	1.5	-
Forty-Eight Insulations Incorporated[b]	June 1977	specialized insulation products (i.e., pipes and vessels)	0.002-0.643 mean = 0.13	-	-
U.S. Mineral Products	December 1974	blowing/pouring wool, specialized insulation products	0.8-2.6[c]	2.4[d]	17

[a] Only one reading (out of 102 readings) had concentration of 2.306 fibers/cc. About 54 percent of airborne fibers were respirable.

[b] Currently not in operation.

[c] Approximately 65 percent of airborne fibers were respirable. The bagger had highest exposure of 2.6 fibers/cc.

[d] Average bulk fiber diameter is 7 um.

Note: See Tables 4-7 for detailed sampling results by plant.

Source: Fowler 1977, 1978a, 1978b, 1980.

4 through 7 summarize airborne fiber concentration data for each job category at each mineral wool plant. The job category with greatest exposure to airborne fibers varied between the four plants surveyed: (1) batt line take-off workers -- Rockwool Industries (see Table 4); (2) cupola leaders and operators, front end leaders, and batt line take-off workers -- U.S.G. (see Table 5); (3) fabrication workers -- Forty-Eight Insulations (see Table 6); and (4) fiber baggers and stitchers -- U.S. Mineral Products (see Table 7). In general, fiber concentrations were less than 1 fiber/cc, and all but 8 personal samples had concentrations less than 0.5 fiber/cc. Several airborne fiber concentrations exceeded 2 fibers/cc; these high concentrations occurred at the cupola and bagger areas. High airborne fiber concentrations found at the cupola area were unexpected since workers in this area are not in direct contact with mineral wool.

Another industry-wide study on exposure of workers to man-made mineral fibers was conducted by an academic institution (Esmen et al. 1979). The three year study encompassed 16 facilities, 5 of which manufacture mineral wool.* The results showed average nominal fiber sizes ranging from 6 to 8 μm. A summary of the characteristics of the facilities surveyed is presented in Table 8. The average number of employees at a plant associated with fiber production is approximately 145 workers, or 75 percent of total plant employment.

Tables 9 and 10 summarize the airborne fiber concentrations measured by optical microscopy and electron microscopy, respectively, at the five plants. The standard deviations of fiber concentrations are also reported. The study grouped different jobs at the plants into six categories:

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* The other 11 facilities produce glass fibers which are discussed in Chapter VII. Company names and facility locations were not disclosed.

Table 4. Summary of Airborne Fiber Concentrations as Determined by Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) at Rockwool Industries

Job Category	Fibers/cc OM (≥1 μm in diameter)	Fibers/cc SEM (≤1 μm in diameter)
Notcher[a]	0.054-0.087	0.056-0.083
Wool Line Taper	0.069	0.064
Wool Line Cleanup	0.083	0.11
Batt Line Taper	0.069	0.042
Batt Line Take-Off	0.32-0.41	0.17-0.44
Batt Line Loader	0.076	0.037
Batt Line Cleanup	0.18	0.20
Maintenance	0.061	0.076
Foreman	0.21	0.11

[a] Notchers are defined as those workers in the cupola area.

Source: Fowler 1977.

Table 5. Summary of Airborne Fiber Concentrations as Determined by Optical Microscopy at U.S.G. Corporation[a]

Job Category	Number of Samples	Fibers/cc Minimum	Maximum	Time Weighted Average[b]	Geometric Mean	Geometric Standard Deviation
Cupola Charger	5	N.D.[c]	0.279	0.150	0.125	3.97
Cupola Leader[d]	3	0.246	0.286	0.257	0.258	1.09
Cupola Operator	13	0.023	2.15	0.544	0.448	2.98
Boiler Operator	9	0.045	0.222	0.118	0.108	1.75
Front End Leader[e]	4	0.066	2.306	0.629	0.302	4.61
Relief and Cleanup	10	0.034	0.464	0.153	0.130	2.00
Batt Machine Tender	3	0.063	0.236	0.140	0.106	2.02
Batt Line Take-Off	5	0.106	0.443	0.244	0.208	1.90
Bagger	13	0.008	0.152	0.063	0.052	2.18
Baler Operator	3	0.068	0.146	0.119	0.107	1.49
Warehouse	4	0.039	0.331	0.133	0.118	2.45
Loader	11	0.040	0.278	0.138	0.115	1.86
Quality Control	5	0.016	0.244	0.100	0.077	2.86
Maintenance	17	0.008	0.355	0.143	0.090	2.83

[a] Formerly called U.S. Gypsum.

[b] "Time weighted averages" were calculated as "flow weighted averages". The nominal initial flow rates were 2.0 liters/minute. The average exposures were calculated by the formula:

$$TWA = \frac{\sum_{i=1}^{n} X_i f_i}{\Sigma f_i}$$

Table 5 (Continued)

where, X_i = the concentration found for the $i^{\underline{th}}$ sample in fiber/cc.

f_i = the total volumetric air flow for the $i^{\underline{th}}$ sample in liters.

[c] N.D. = Not detected. The limit of detection is 0.005 fibers/cc.

[d] The cupola leader is responsible for maintaining adequate temperature and loading in the cupola. He supervises the cupola charger and operator.

[e] The front end leader is responsible for the operation and output of the batt machine, baler, and bagger. His station is near the batt machine, and he moves throughout the production area.

Source: Fowler 1978b.

Table 6. Summary of Airborne Fiber Concentrations as Determined by Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) at Forty-Eight Insulations, Inc.[a]

Job Category	Fibers/cc OM (≥1 μm in diameter)	Fibers/cc SEM (≤1 μm in diameter)
Cupola Operator	0.245	0.221
Cupola Charger	0.312	0.196
Crew (Take-Off)[b]	0.067-0.096	0.041-0.069
Crew (Fabrication)[c]	0.185-0.325	0.239-0.565
Warehouse Loader	0.074	0.193
Maintenance	0.157	0.172
Laboratory Technician[d]	0.220	0.108

[a] Temporarily closed. Company representative stated that when the plant is in operation, the exposure to airborne fibers is comparable to that in 1977.

[b] This production crew (take-off operators) is mainly responsible for the packaging area. This is a general labor category since these workers may also work in the fabrication shop.

[c] These workers are involved in the packaging of products which require additional covering (such as wiring of mineral wool blankets).

[d] Performs tests on mineral wool products.

Source: Fowler 1978a.

Table 7. Airborne Fiber Concentrations As Determined By Phase Contrast Optical Microscopy at U.S. Mineral Products

Job or Sample Location	Fibers/cc
Fiber Bagger	2.6
Bag Stitcher	2.1
Bag Car Loader	0.8
Stationary 15 ft. from Bagging	1.5
Stationary 15 ft. from Bagging	1.3

Source: Dement 1975.

Table 8. Summary of Selected Characteristics of Mineral Fiber Facilities Surveyed

Facility	Type of Fiber Produced	Material	Average Nominal Fiber Size, um	Approximate Total Number of Employees	Approximate Number of Employees Associated With Fiber Production	Manufacturing Level	Number of Dust Samples
Plant 1	Loose	Slag	6	80	65	Moderate	55
Plant 2	Loose	Slag	8	150	120	Light	60
Plant 3	Loose	Slag	6	400	265	Very Heavy	63
Plant 4	Loose	Slag	7	70	N/A	None[a]	66
Plant 5	Loose	Rock and Slag	7	150	130	Heavy	72

N/A = Not available.

[a] Consumer products were not produced at this plant.

Source: Esmen et al. 1979.

Table 9. Summary of Fiber Concentration as Determined by Optical Microscopy (≥1 micron in diameter) Expressed as Fibers/cc

	Plant Operations													
	Forming		Production		Manufacturing		Maintenance		Quality Control		Shipping		Overall	
Facility	C[a]	σ[b]	C	σ	C	σ	C	σ	C	σ	C	σ	C	σ
1	0.071	0.032	0.165	0.14	0.122	0.11	0.080	0.052	0.192	0.16	0.065	0.06	0.11	0.12
2	0.015	0.010	0.028	0.023	0.029	0.023	0.016	0.01	0.025	-	0.026	0.012	0.024	0.018
3	0.146	0.028	0.235	0.12	0.429	0.32	0.438	0.37	-	-	0.154	0.17	0.34	0.35
4	0.092	0.109	0.049	0.032	0.038	0.029	0.041	0.039	0.076	0.077	0.025	0.019	0.053	0.049
5	0.578	-	0.083	0.056	0.111	0.17	0.093	0.08	-	-	0.032	0.016	0.097	0.10

[a] C = Arithmetic Mean - f/cc

[b] σ = Standard Deviation - f/cc

Source: Esmen et al. 1979.

Table 10. Summary of Fiber Concentration as Determined by Electron Microscopy (<l um in diameter) Expressed as Fibers/cc[a]

	Plant Operations													
	Forming		Production		Manufacturing		Maintenance		Quality Control		Shipping		Overall	
Facility	C[b]	σ[c]	C	σ	C	σ	C	σ	C	σ	C	σ	C	σ
1	0.04	0.027	0.041	0.021	0.031	0.029	0.038	0.037	0.071	0.081	0.0099	0.006	0.035	0.031
2	0.01	0.012	0.008	0.0065	0.004	0.002	0.008	0.0051	0.019	-	0.006	0.002	0.008	0.006
4	0.123	0.089	0.024	0.023	0.023	0.025	0.013	0.013	0.014	0.013	0.013	0.0085	0.033	0.056
5	0.036	-	0.025	0.032	0.031	0.035	0.023	0.019	-	-	0.006	0.006	0.024	0.036

[a] Electron microscopic data for facility 3 is not reported because the analysis method used for this facility was not as reliable as the method used for the reported data.

[b] C -- Arithmetic Mean - f/cc

[c] σ -- Standard Deviation - f/cc

Source: Esmen et al. 1979.

(1) Forming -- workers at the cupola area.

(2) Production -- workers who are in direct contact with fibers but are not involved in cutting and packaging operations.

(3) Manufacturing -- workers involved in cutting and packaging operations.

(4) Maintenance -- this included maintenance workers who repair production machinery, and also the cleaning workers.

(5) Quality Control -- workers who sample and run tests on the fiber product.

(6) Shipping -- workers involved in transport of packaged material (forklift operators).

Personal samples were collected within the breathing zones of the workers. Workers from various job sites were selected randomly because it was not possible to sample all individuals in each job area. Samples were obtained by having the worker wear a filter and pump while he performed his work.

Data in Table 9 are determined by optical microscopy which identifies only those fibers that are greater than or equal to 1 µm in diameter. Data on fibers with diameters less than one micron are presented in Table 10; these fibers are identified by electron microscopy. The overall average concentrations of airborne fibers with diameters greater than or equal to 1 µm ranged from 0.024 to 0.34 fibers/cc (average concentrations for job categories ranged from 0.01-0.578 fibers/cc). The overall average fiber concentrations for fibers less than 1 µm in diameter ranged from 0.008 to 0.035 fibers/cc (average concentrations for job categories ranged from 0.002-0.123 fibers/cc). Concentrations of the smaller fibers (≤1 µm) are about one order of magnitude lower than concentrations of the larger fibers (≥1 µm). Approximately 50 to 60 percent of all airborne fibers were less than 3 µm in diameter (i.e., respirable). Eighty percent of the airborne fibers were less than 50 μm in length, and about 10 percent of the airborne fibers had lengths less than 10 μm. Comparison of fiber concentrations among different categories show that all concentrations are roughly comparable (less than 0.6 fiber/cc). Surprisingly, workers who are in almost constant contact with fibers (production workers) experience about the same level of exposure to airborne fibers as those who are infrequently in contact with fibers (i.e., shipping workers). Despite operational diversities among mineral wool plants, fiber concentration data are similar for all facilities except for Facility 3 (see Table 9). Fiber concentrations for each job category at Facility 3 are consistently higher than those found at other facilities possibly due to the fact that the manufacturing level at Facility 3 is heavier than that of other facilities (see Table 8). Likewise, Facility 2 probably has relatively low fiber concentrations as shown in both Tables 9 and 10 because the level of manufacturing at this facility is rather light.

In addition to the studies above, industrial hygiene surveys were also carried out at production plants in Denmark, Finland, France, Italy, Norway, Sweden, and the United Kingdom. The surveys were taken at 13 man-made mineral fiber production plants (Ottery et al. 1982). The surveys encompassed 6 rock wool plants. Insulation wools are manufactured at these plants by the blowing and/or centrifuging processes with nominal diameters of about 6 μm. Workers, selected randomly, were asked to wear sampling equipment during their working shift. Sampling equipment consisted of a filter holder (attached to the worker's lapel) and a sampling pump (attached to a belt worn around the waist). Each sampling session lasted between 7 and 8 hours. Scanning electron microscopy was used to measure fiber size distribution, and phase contrast microscopy was used to measure fiber concentrations.

The total (respirable and non-respirable) mean fiber concentrations measured varied from 0.01 fiber/cc to 0.68 fiber/cc; the airborne concentrations were generally less than 0.1 fiber/cc. Workers involved in secondary processing of mineral wool into various specialized products experienced higher levels of airborne fiber concentrations (0.68 fiber/cc average concentrations with individual concentrations up to 2 fibers/cc) than those workers involved in primary manufacturing. The mean respirable fiber concentrations for all plants were "generally very low" with most concentrations less than 0.08 fiber/cc. Workers in plants manufacturing specialized products were again exposed to higher respirable fiber concentrations, but not greater than 1 fiber/cc. The median airborne fiber lengths and diameters found at these rock wool plants ranged from 10-20 µm and 1.2-2 µm, respectively.

Another European study by Head and Wagg (1980) presented occupational exposure data to insulation wools for one mineral wool plant and three fiber-glass plants. The study reported a mean respirable fiber concentration of 0.37 fiber/cc (individual range 0.003-1.17 fibers/cc) for the mineral wool plant. Overall, 79 percent (range 77-81 percent) of the airborne fibers were respirable. Respirability is defined here as those fibers with diameters less than 3 µm and lengths greater than 5 µm. These fiber concentrations were measured by optical microscopy; sampling durations were not longer than 4 hours. This mineral wool plant employed the centrifugal spinning method and produced fibers with nominal diameters ranging from 4 to 9 µm.

Another survey was performed at three rock wool plants in Poland (Indulski et al. 1982). Only fibers greater than 5 µm in length and less than 3 µm in diameter (i.e., respirable fibers) were counted (by optical microscopy). Mean fiber concentrations ranged from 0.10 fiber/cc to 0.65 fiber/cc. The median fiber diameter ranged from 1.35 µm to 2.20 µm, and the median fiber length ranged from 10 µm to 41 µm. Fifty-seven to 84 percent of the airborne fibers were respirable.

Two other studies were conducted at rock wool plants in Sweden (Malmberg et al. 1982) and Yugoslavia (Skuric and Stahuljak-Beritic 1982). Both studies reported mean respirable fiber concentrations of less than 0.5 fiber/cc. Table 11 presents exposure data from the European studies discussed above.

B. Fiber Use -- Installation and Removal of Insulation Materials

A major use of mineral wool is as an insulation material for residential, commercial, and industrial installations. Applications of mineral wool that are of concern due to potential for fiber exposure include:

- loose wool -- which is blown into structural spaces of residential and/or commercial buildings;
- batts or blankets -- which are relatively loose and light, and can be shaped to fill void spaces within the structural members of residential and commercial buildings;
- high-density material -- which are used for insulating pipes, ducts, boilers, and other equipment in commercial and industrial buildings; and
- fire proofing material -- which is sprayed on steel girders in buildings.

In addition, building demolitions are also another area of concern with respect to fiber exposure.

1. Installation Contractors

The installation of mineral wool insulation for the above applications is performed by installation contractors (e.g., Carney Insulation; Ruppert Brothers, Inc.; St. Louis Home Insulators). There are more than 200* insula-

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* Estimated from the "1985 and 1986 Directory and Buyer's Guide" published by the National Insulation Contractors Association (NICA).

Table 11. Summary of Mineral Wool Exposure Data from European Studies

Plant Location	Number of Mineral Wool Plants Investigated	Nominal Fiber Diameter (um)	Mean Respirable Fiber Concentration (fibers/cc) (range)	Percent Respirable Fiber	Median Diameter (um)	Median Length (um)	Source
Various European Countries	6	6	<0.08	N/A	1.2-2.0	10-20	Ottery et al. 1982
United Kingdom	1	4-9	0.37 (0.003-1.17)	79[a]	-	-	Head and Wagg 1980.
Poland	3	N/A	(0.10-0.65)	57-84[a]	1.35-2.20	10-40	Indulski et al. 1982.
Sweden	1	N/A	0.19 (0.03-0.85)	N/A	N/A	N/A	Malmberg et al. 1982.
Yugoslavia	3	N/A	(0.003-0.463)	N/A	N/A	N/A	Skuric and Stahuljak-Beritic 1982.

N/A = Not available.

[a] Respirable fibers defined as those fibers with diameter less than 3 um and length greater than 5 um.

tion contractors in the U.S., and most contractors operate at more than one location. The total number of workers employed by the insulation contractors varies widely from as few as 4 workers to as many as 60 workers, depending on the contractor's specializations in the industry (Fowler 1978d, 1978e; Fisher Insulation 1986; Ruppert Brothers 1986). These installation contractors often use various insulation materials such as fiberglass, ceramic fibers, mineral wool, and other materials (e.g., Fisher Insulation; Reinke Jr. and Co.; Fibrex Inc.; Partek Insulations, Inc.). Industry contacts indicated that approximately 80 percent of the insulation material used today is fiberglass, about 10 percent is mineral wool, and 10 percent is other materials (Fisher Insulation 1986, National Insulation Contractors Association 1986). Fiberglass is the product most directly competitive with mineral wool (Fisher Insulation 1986, Fowler 1980). The choice between using mineral wool versus fiberglass depends on the availability of mineral wool for that particular geographical area (Fisher Insulation 1986, Fowler 1980). Transportation costs make it unattractive to use mineral wool where it is not available locally (Fisher Insulation 1986, National Insulation Contractors Association 1986).

2. Installation Processes/Extent of Potential Exposure

The installation procedures for mineral wool and fiberglass insulation materials are the same (Fisher Insulation 1986, National Insulation Contractors Association 1986); refer to Chapter VII, Section B.3 for details on installation procedures of insulating materials. According to industry sources, the installation procedures for insulation materials have not changed since the 1970's (Fisher Insulation 1986, NICA 1986). Potential exposures during a variety of installation operations are discussed below.

a. Installation of Blowing Wool and Batts/Blankets

(1) Process Description and Points of Exposure

Mineral wool blowing wool is usually applied to attics of residential and commercial buildings for thermal insulation. The installation work can take place at either old or new construction sites. The installation of blowing wool and insulation batts/blankets is labor intensive. Blowing operations usually involve two workers: one worker emptying the wool bags into the blower, and the other worker directing the flow of the material (from a hose) into the attic or wall spaces. Batt/blanket operations may require 2 to 3 workers. Installation involves unrolling the batts/blankets, cutting the batts/blankets into the desired size, and stapling them between wall studs and ceiling joists. Due to the nature of the work, ventilation is generally poor for these workers. Engineering controls are almost impossible to apply. Personal protective equipment includes dust masks, safety glasses, and gloves. The installation processes are discussed in more detail in Chapter VII, Section B.3.

The installation time required for each application varies between jobs. One installation contractor estimates that it takes about 70 minutes to cover a 1,000 square feet space with blowing wool (Fisher Insulation 1986).

(2) Extent of Potential Exposure

Extensive studies of two installation sites were performed during the period from 1976 to 1977 (Fowler 1978c, 1978d, 1980). The two installation operations studied were the application of blowing wool into attics or wall spaces using a pneumatic blower, and application of mineral wool batts to walls and ceilings for thermal insulation. The same air sampling method was used for both studies. Personal air samples were taken by clipping a pair of air sampling filters to the collar of the worker's shirt or jacket, one on each side and as close as possible to his breathing zone. The pair of pumps was clipped to the worker's belt (Fowler 1978c, 1978d).

The material used by the insulation contractor (Modern Home Insulation, Inc.) in the first study (Fowler 1978c) was predominantly mineral wool (approximately 85 percent). The blowing wool operation resulted in fiber concentrations of 0.035 fibers/cc for the worker (in the truck) who empties the blowing wool into the blower and 0.552 fibers/cc for the worker who directs the flow of the mineral wool to the desired area in the house. Exposure is higher for the worker inside the house due to the lack of ventilation usually found in attics where blowing wool is commonly applied.

Fiber concentrations ranged from 0.087 to 1.359 fibers/cc (as measured by optical microscopy) at Shepherd Insulation for the second study (Fowler 1978d) which also focused on a blowing wool operation. The fiber concentrations for the installer located in the house were seven times greater than those experienced by the installer located in the truck, 0.856-1.359 fibers/cc versus 0.087-0.238 fibers/cc. The air sampling results for this study are shown in Table 12. Fiber concentrations observed by scanning electron microscopy (SEM) are significantly higher than the optical microscopy (OM) results for the two samples examined. The sizes of the fibers determined by OM have a geometric mean diameter of 1.6 μm and a geometric mean length of 12 μm, compared to fiber sizes determined by SEM of 0.9 μm and 10 μm for geometric mean diameter and length, respectively. The respirable percentage of airborne fibers was not determined. Time-weighted average concentration for all samples measured by OM is 0.6 fiber/cc. This average concentration is probably more representative of the exposure of the workers throughout a "typical" working day since about 25 percent of their day is spent traveling to different job sites and setting up equipment (Fowler 1978d). Therefore,

Table 13. Respirable Fiber Concentrations -- Blowing Wool Installation

Job Classification	Number of Samples	Respirable Fiber Concentration (fibers/cc) Average[a]	Range	Average Respirable Fraction[b]
Helper	9	0.53	0.041-2.03	0.71
Blower	23	4.2	0.50-14.8	0.48
Feeder	9	1.4	0.26-4.4	0.74

[a] Arithmetic mean.

[b] Arithmetic mean value of respirable fiber concentration/ total fiber concentration.

Source: Esmen et al. 1981.

Table 14 presents the time-weighted average total and respirable fiber concentrations. The time-weighted average (TWA) total fiber concentration for mineral wool attic insulation workers ranges from 0.4-9.9 fiber/cc with an average of 3.1 fibers/cc. The TWA respirable concentration for these same workers ranges from 0.29 to 6.3 fibers/cc, with an average of 2 fibers/cc. Approximately 60-70 percent of the airborne fibers are respirable. This study estimated a typical work day for an insulation installer to be about 4 hours; the rest of the installer's time is spent travelling to different job sites. If these workers are assumed to be in a fiber-free environment during the time they spend in transit to and from work sites, their 8-hr TWA values would be expected to be about one-half of the values shown in Table 14 (Esmen et al. 1981). Each sample represents a distinct work period and does not represent the daily 8-hour exposure. Sampling durations, however, were not reported. Table 15 illustrates the airborne fiber diameter distribution for the blowing wool installation operation. The median fiber diameters found for the roofer, blower, and feeder are 1.6, 3.2, and 1.1 microns, respectively. Median fiber length ranged from 19.0-43.0 microns between these three job classifications.

Schneider (1982) evaluated exposure to man-made mineral fibers (MMMF) in various insulation fabrication and installation operations (see Table 16). Average airborne fiber concentrations generated during installation of insulation in new buildings (probably batt insulation), installation of acoustical ceiling tile, and duct insulation fabrication and installation were all below 0.03 fibers/cc, with an occasional sample reaching 0.5 fibers/cc during duct fabrication. Blowing wool insulation installation again generated high exposures, mean concentrations ranged from 0.35-3.82 fibers/cc. The blower for the attic insulation is exposed to by far the highest mean fiber concentration, 3.82 fibers/cc and ranging from as low as 0.19 fiber/cc to as

Table 12. Shepherd Insulation -- Air Sampling Results

Area of Job Category	OM[a] (fibers/cc)	SEM[b] (fibers/cc)
Insulation Installer		
-- In Truck	0.087	-
	0.238	0.57
-- In House	1.359	-
	0.856	-
Area Sampler[c] -- Inside House	1.114	-
	0.723	5.48
TWA[d]	0.606	

[a] Concentrations of fibers ≥1 μm in diameter measured by optical microscopy (OM).

[b] Concentrations of fibers ≤1 μm in diameter measured by scanning electron microscopy (SEM).

[c] Area sampler is inside the attic.

[d] TWA = overall time-weighted average concentration for worker inside the attic, worker in the truck, and the stationary samplers inside the attic. This was calculated as "flow-weighted average," see Table 5.

Source: Fowler 1978d.

the true average exposures experienced by these workers may be about 25 percent less, or about 0.45 fiber/cc. The bulk material (≥90 percent rock wool) was also examined for fiber dimensions. A sample taken from the bag on the truck had a geometric mean diameter of 3.7 μm, and a second sample taken as the wool left the hose inside the house showed a geometric mean diameter of 4.8 μm.

Both insulation contractors performed installation of both blowing wool and batts/blankets; however, air measurements were taken only during the blowing operation since blowing wool installation was believed to generate higher exposure levels to airborne fibers. Approximately half of the jobs performed by these insulation contractors are "blowing" applications. The application of blowing wool is believed to generate the highest exposure to airborne fibers (compared to other applications) because blowing wool is normally installed in confined spaces (e.g., in attics) which have almost no ventilation.

Another major industrywide study on worker exposure to man-made mineral fibers during the installation of insulation materials was performed by Esmen et al. (1981). Data were collected at a number of commercial and residential buildings under construction and at a housing complex. Applications included blowing wool operations, duct insulation, and general building insulation with batts or blankets; however, only the blowing operations involved the use of mineral wool. Respirable fiber concentrations (defined here as fibers less than 3 μm in diameter) for blowing wool installation are presented in Table 13. Blowers of attic insulation were exposed to the highest respirable fiber concentrations, ranging from 0.50-14.8 fibers/cc with an average respirable fiber concentration of 4.2 fibers/cc. However, the average respirable fraction for the blower is lower than those of the helper and the feeder.

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range from 20 to 110 minutes. The old insulation material has no binder or dust suppressing substances (i.e., oil) on it; these materials could have deteriorated since 1951 (Schneider 1979).

In addition, air samples were also taken when the same workers were installing new MMMF insulation in the same loft. The results showed a very low 8-hr TWA of 0.5 fiber/cc for respirable fibers; 84 percent of the fibers were respirable. The fiber exposure level during removal work is clearly much higher than during the installation of new insulating material. (It was noted that the old and the modern types of MMMF are very similar in fiber dimensions (Schneider 1979).)

The Schneider study did not supply any information about duration of exposure or protective equipment used.

3. <u>Conclusion</u>

Several conclusions can be made about the potential for fiber exposure during installation of insulation materials. Engineering controls are difficult to apply to many of the workplace environments in which mineral wool insulation products are used (Fisher Insulation 1986, NICA 1986, Fowler 1980). The major method of controlling worker exposures during installation of insulation materials is the use of personal protective devices such as disposable respirators, safety glasses, and gloves (Fisher Insulation 1986, NICA 1986, Fowler 1980). The use of personal protective devices is optional, and in some cases, usage of disposable respirators are limited because of difficulty of their usage.

Airborne fiber concentrations observed during the installation of insulation products showed great variability due to the variety of mineral wool products used and the range of work operations (Schneider 1982, Fowler 1980). Workplace setting varies from site to site and between various applications. Insulation work can take place in open air, in well ventilated workplaces, and in confined and poorly ventilated spaces. Measurements of fiber concentrations are, therefore, only representative of the particular operation or product. Insulation contractors have higher exposures and more variable exposures to airborne fibers than production workers (Fowler 1980, Esmen 1981, Schneider 1982). In general, installation workers are also exposed to smaller fibers than production workers (Fowler 1980). The installation of industrial insulation such as insulating pipes, ducts, boilers, and other equipment generates lower levels of fiber exposure than blowing wool and fireproofing installation operations. Blowing wool installers are exposed to the highest fiber concentrations (Esmen 1981, Schneider 1982, Fowler 1980). It is difficult to establish a pattern for exposure to airborne fibers in the insulation industry because of the great variety of construction materials, installation methods, and work practices.

The duration of exposure varies from site to site depending on the amount of work required. Installation workers spend a good portion of their time traveling between work sites and performing different jobs often using different fibers. A typical work day was estimated to include about 4 hours of exposure to fibers during the actual installation work (Esmen 1981, Schneider 1982). Fiber exposure levels, therefore, do not accurately represent the daily exposure as they did in the case of production workers.

Table 18. Frederick Meiswinkel, Inc. -- Air Sampling Results As Determined by Optical Microscopy

Area	Job Title	Fibers/cc
Lower Floor -- Near Hopper	Hod Carrier	0.496
	Area Sample	0.086
Upper Floor -- Application	Plasterer	0.639
		0.384
	Area Sample	0.020

Source: Fowler 1978f.

fiber/cc (Fowler 1978f), and area fiber concentrations ranged from 0.02-0.086 fiber/cc. The hod carrier and plasterer were exposed to approximately the same fiber levels. Samples taken near the plasterer had a geometric mean length of 45 μm (standard deviation of 3.9 μm) and a geometric diameter of 2.7 μm (standard deviation of 1.9 μm). Samples taken for the hod carrier were shorter and finer, with geometric length of 28 μm (standard deviation of 3.9 μm) and geometric diameter equal to 2.2 μm (standard deviation of 1.9 μm). The respirable percentage of airborne fibers was not determined.

The study by Head and Wagg (1980), discussed earlier, also reported worker exposure levels during the application of mineral wool, as a fireproofing material, to structural steel at two sites. The results showed fiber concentrations of 0.72 and 0.82 fiber/cc with a range of 0.16 to 2.57 fibers/cc. Eleven samples were taken at each work site and were analyzed by optical microscopy.

d. <u>Building Demolition</u>

Any of the contractors who install insulation materials may also be involved in removal of insulation materals. No studies on building demolition (removal of mineral wool insulation products from existing structures) were found for user industries in the U.S.; however, a Scandinavian study of exposures during the removal of insulation material made of man-made mineral fibers (MMMF) was located (Schneider 1979). Measurements were taken on a loft of a terrace house where three men were removing MMMF roll mats from between two sheets of paper. The roll mats were put on the loft in 1951. Individual samples showed fiber concentrations ranging from 4-25 fibers/cc; 90 percent of the fibers were respirable. The 8-hour time-weighted average (TWA) for respirable fibers is 9 fibers/cc. Sample times standard deviation of 2 µm. Airborne fiber concentrations and fiber diameters were determined using optical microscopy.

Head and Wagg (1980) evaluated fiber exposure during the installation of industrial engine exhaust insulation at two plants. Fifteen samples (breathing zone and static samples) were taken. The mean respirable fiber concentrations were 0.07 fiber/cc and 0.10 fiber/cc for the two plants with a range of 0.02-0.36 fiber/cc. Respirable fiber is defined here as fiber having a diameter less than 3 µm and length greater than 5 µm. Fiber measurements were determined by optical microscopy.

c. Installation of Fireproofing Materials

(1) Process Description and Points of Exposure

Process Description and Automation. The application of fireproofing by a crew of plasterers occurs about once per month; workers spend significant amounts of their time in application of more typical plastering materials (Fowler 1978f). Fibrous fireproofing material, containing fairly high concentrations of mineral wool fibers, is applied to structural steel supporting members and roof decks in buildings under construction. The material is emptied into an electrically-driven blower and is then blown through a corrugated flexible hose to the point of application (similar to blowing wool installation). At the hose nozzle, the mineral wool is mixed with a spray of water from a nozzle in the center of the hose. The person directing the material to the desired area to be covered is called the plasterer, and his assistant is called the hod carrier. Only two workers are needed for small operations. On larger jobs, a laborer may be used as well. During installation operations, the plasterer spends about 70-80 percent of his time (at a job site) directing the flow of the material onto the beams and decking being protected. The plasterer is relatively close to the surface of application; his face is usually 2-3 feet from the surface of application so that he is liberally coated with the fireproofing material from the spraying in a relatively short time (Fowler 1978f). The hod carrier has three principal duties: he empties the bags of material into the hopper; he moves the scaffolding for the plasterer; and he cleans up the job site. Most of his time is spent near the hopper, emptying the bags into the hopper.

Engineering Controls and Personal Protective Equipment. The process of applying fireproofing material to structural steel in buildings is not conducive to engineering controls. Personal protective equipment is the only appropriate method of reducing worker exposures. Respiratory protection devices are available; however, plasterers choose not to wear them. Fowler (1978f) indicates that the plasterer is aware of the potential exposure to fiber but is reluctant to wear a respirator because of problems with fogging and collapsing of the disposable respirator due to the collection of moisture from exhaled air and from wetted material that rebounds from the surfaces being sprayed. Both the workers wore safety helmets, and the plasterer also wore safety glasses. In addition, the plasterer placed a "hood" of polyethylene film around his head to prevent the material being sprayed from falling down his neck and getting into his hair. The plasterer was noted to have significant amounts of material on the glasses, helmet, and "hood" that he wore. Ventilation around the work area was generally good. The area of application was open, and wind velocity was somewhat higher than normal (Fowler 1978f).

(2) Extent of Potential Exposure

Table 18 summarizes breathing zone fiber concentrations for fireproofing workers of Frederick Meiswinkel, Inc. Breathing zone fiber concentrations, measured by optical microscopy, ranged from 0.384-0.639

specific job categories for this installation operation; both workers share the job responsibilities equally by either "trading-off" or working together on specific tasks (Fowler 1978e). Other methods of applying high-density insulation materials to industrial pipes, boilers, ducts, and equipment are discussed in Chapter VII, Section B.3. The basic procedures for installing such materials are similar and labor intensive.

No engineering controls are used during installation work. Because of the nature of insulation installation work, engineering controls have traditionally been difficult to apply (Fisher Installation 1986, National Insulation Contractors Association 1986, Fowler 1980). Workers were supplied with approved disposable respiratory protective masks; however, they chose not to use these masks.

(2) Extent of Potential Exposure

Table 17 presents the results of air sampling for workers (employees of Pacor Inc.) applying mineral wool blanket to a combustion gas duct (Fowler 1978e). Area fiber concentrations ranged from less than 0.01 fiber/cc to 0.185 fiber/cc. The time-weighted average for all personal samples was 0.076 fiber/cc. As expected, the fiber concentration levels for this type of insulation installation are lower than the levels found during the installation of blowing wool and are below the exposure level of 3 fibers/cc recommended by OSHA. The fibers to which these workers are exposed are similar in size to those to which mineral wool production workers are exposed; however, the airborne fiber concentrations levels are higher at the installation sites than at the production sites. The geometric mean diameter of airborne fibers was 1.9 μm and the geometric mean length was 11.8 μm. Bulk material samples had a geometric mean diameter of 3.4 μm with a

Table 17. Pacor Inc. -- Air Sampling Results As Determined by Optical Microscopy

Area/Job Function	Fibers/cc
PERSONAL SAMPLES	
Applying Mineral Wool	0.108
Mixing Mud and Applying	0.107
	0.067
Mixing Mud	0.072
	0.032
	TWA[a] = 0.076
AREA SAMPLES	
Near Scaffold	0.056
	0.01
	0.08
	0.01
Near Door	0.010
	0.024
	0.185
	0.093

[a] Time-weighted average was calculated as flow-weighted average, see Table 5.

Source: Fowler 1978e.

Table 16. User Industries of Man-Made Mineral Fibers -- Summary of Fiber Concentrations, United States Survey

	Total Fibers per cc	
	Mean	Range
Attic Insulation by Blowing:		
Helper	0.35	0.015-2.03
Blower	3.82	0.19-20.1
Feeder	0.63	0-0.25
Insulation of New Buildings	0.02	0-0.085
Acoustical Ceiling Tile	0.01	0.002-0.028
Duct Installation and Insulation	0.03	0.005-0.11
Duct Fabrication	0.02	0.007-0.49

Source: Schneider 1982.

high as 20.1 fibers/cc. This result is expected due to the nature of the work involved in installation of attic insulation and the poor ventilation found in attics. One disadvantage of these data is that the fiber concentrations presented included both mineral wool and fiberglass; no information was given to differentiate between the fibers.

Schneider (1982) also presented measurements from British, Swedish, and Danish surveys. Measurements from the British survey also show high exposures for workers involved in attic insulation installation using loose fill MMMF. The respirable concentration to which these workers are exposed ranges from 0.54 to 20.9 fibers/cc, with a mean of 8.19 fibers/cc. The Swedish and Danish measurements, however, show lower exposure during attic insulation of 1.11 and 0.89 fibers/cc (mean respirable fiber concentrations), respectively. Schneider stated that it is very difficult to estimate the average exposure of workers in the insulation installation industry. High variability in measurements results from differences in work settings, materials, and work practices. Fiber concentrations in all surveys were examined by phase contrast optical microscopy.

b. Installation of High-Density Materials

The installation of high-density materials containing mineral wool is relatively rare. A job where this is specified occurs only once every few months for most installation contractors.

(1) Process Description and Points of Exposure

Two workers are required to install industrial insulation blanket for applications such as effluent combustion gas ducts leading to the discharge stack from commercial steam heating plant boilers. The workers apply blankets to the duct using a "pin gun". The blanket is then covered with wire mesh ("chicken wire") followed by hydraulic cement. There are no

Table 14. Time-Weighted Average (TWA) Total and Respirable Fiber Concentrations Calculated from Personal Sampling Data of Exposures for Less Than a Full Work Day[a]

	Fiber Concentrations (fibers/cc)	
	Range	Average[b]
TWA -- Total Fiber Concentration		
-- Optical Microscopy	0.35-7.8	2.4
-- Electron and Optical Microscopy	0.40-9.9	3.1
TWA -- Respirable Fiber Concentration		
-- Electron and Optical Microscopy	0.29-6.3	2.0

[a] Not an 8-hour TWA. Workers spend about half of their working day travelling to different job sites during which time no measurements were taken. Sample durations were not reported, but samples were taken during distinct short-term operations.

[b] Workers rotate tasks. Each individual's exposure was calculated, and these values were averaged.

Source: Esmen et al. 1981.

Table 15. Size Characteristics of Airborne Fibers -- Mineral Wool Blowing Installation

Job Classification	Fiber Diameter ≤1 μm, Fiber Length ≤5 μm	Fiber Diameter ≤1 μm, Fiber Length ≥5 μm	Fiber Diameter 1-3 μm	Fiber Diameter ≥3 μm	Median Diameter (μm)	Median Length (μm)
	Occurrence of Fiber Diameter/Length Classes As Percentages of Total Fibers					
Roofer	7.1	25.7	38.0	29.2	1.6	31.0
Blower	5.6	21.3	21.4	51.7	3.2	43.0
Feeder	20.4	27.8	26.1	25.7	1.1	19.0

Source: Esmen et al. 1981.

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IX. POLYOLEFIN FIBER

Polyolefin fibers are manufactured fibers in which the fiber-forming substance is any long-chain, synthetic polymer of at least 85 percent by weight of ethylene, propylene, or other olefin unit. The olefin fibers of commercial importance are polypropylene and, to a lesser extent, polyethylene (Buchanan 1984). About 95 percent of polyolefin fibers are made from polypropylene (Ahmed 1982).

There are many commercial applications for polyolefin fibers. The largest application for polyolefin is in the carpet and rug industry where polyolefin fibers are used to produce primary and secondary carpet backings. Home furnishings (e.g., upholstery, drapes, and bedding) are also main use areas for polyolefin fibers. The use of polyolefin fiber in apparel has been restricted because of its low melting temperature which makes ironing of polyolefin fabrics impossible (Buchanan 1984).

A. Fiber Production

1. Fiber Producers

A recent market study on polyolefin fibers conducted by ICF (1986a) identified 87 polyolefin fiber manufacturers in the United States. Of these manufacturers, Hercules is the largest producer of multifilament, monofilament, and staple fibers. Amoco Fabrics, Phillips Fibers, E.I. duPont de Nemours & Company (hereafter referred to as Dupont), and Exxon Chemical Americas are also major producers of polyolefin fibers.

Polyolefin products produced by these companies include monofilament yarn, multifilament yarn, staple fiber, tape and fibrillated film yarn, spun-bonded fabric, synthetic pulp, and microfiber. As will become obvious in the following definitions and process descriptions, some of these products are not fibrous (e.g.,tape and fibrillated film yarn) or have extremely large diameters (e.g., monofilament yarn). Because of the length of the polyolefin fiber producer list, an abridged version which focuses on producers of the smaller diameter polyolefin fibers (microfibers, synthetic pulp, and staple fiber) which are of most concern with respect to exposure potential is presented in Table 1.

2. Fiber Production Process/Potential Exposure Points

The information discussed in this section is of a general nature since details of actual practices used by the various fiber manufacturers differ and are considered proprietary information. Information on handling procedures on fiber production lines and levels of automation were not available.

a. Process Description and Automation

Polyolefin fibers are currently available in seven main fiber classes (Textile Economics Bureau 1984, Ahmed 1982) which are:

- Monofilament yarn -- filaments having cross-sectional diameter of about 153.8 μm or larger (Ahmed 1982). One manufacturer reported a cross-sectional diameter of 10,000 μm (Fibers Fabrics of Georgia 1986);
- Multifilament yarn -- includes untextured straight filament yarns as well as textured or continuous filament yarns. Each filament* has a cross-sectional diameter of less than 38.5 μm (Ahmed 1982). Another source gave a range of 5-20 μm for the cross-sectional diameter (Buchanan 1986);
- Staple fiber -- multifilament yarn cut into 1-8 inch lengths and for use in either woven or nonwoven form (Ahmed 1982);
- Tape and fibrillated film yarn -- tape and film yarn have large rectangular cross-sectional diameters (Ahmed 1982, Exxon Chemical 1986a). The "film yarn" resembles a ribbon or a piece of cassette tape. The normal thickness of tape ranges from 2.54-12.7 μm and the thickness of fibrillated film ranges from 2.54-6.35 μm

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* Each filament in a multifilament yarn is not equivalent to a monofilament. Each filament is similar in structure to a monofilament, but the cross-sectional diameter is much smaller.

Table 1. U.S. Polyolefin Microfiber, Synthetic Pulp, and Staple Fiber Producers, Plant Sites, and Plant Employment

Polyolefin Fiber Class	Company and Plant Site(s)	Plant Employment
Microfibers[a]	Riegel Products Corporation	
	-- Milford, NJ[b]	635
	The 3M Company[c]	
	-- Prairie du Chien, WI	N/A
	Kimberly-Clark Corporation	
	-- Balfour, NC[b]	625
Synthetic Pulp	Hercules Inc.[c]	
	-- LaPorte, TX	N/A
	Mini Fibers, Inc.[d]	
	-- Johnson City, TN	35
Staple Fiber	Amoco Fabrics Company	
	-- Andalusia, AL	15
	-- Roanoke, AL	550
	-- Bainbridge, GA (2 plants)	7,275
	-- Hazlehurst, GA	1,500
	-- Nashville, GA	1,100
	-- Lowell, NC	325
	-- Afton, VA	58
		10,823
	Avtex Fibers	
	-- Front Royal, VA	2,500
	Hercules Inc.	
	-- Covington, VA	1,400
	-- Oxford, GA	1,000

Table 1 (Continued)

Polyolefin Fiber Class	Company and Plant Site(s)	Plant Employment
Staple Fiber (Continued)	Integrated Products, Inc.	
	-- Rome, GA	29
	Phillips Fibers Corporation	
	-- Rocky Mountain, NC	365[e]
	-- Seneca, SC	250
	-- Spartanburg, SC	600[f]
		1,215
	Stevens Linen Associates, Inc.	
	-- Webster, MA	13
	-- Dudley, MA (2 plants)	325
		338

N/A = Not available.

a
All microfibers are made from polypropylene.

b
Also produce spun-bonded fabric.

c
Refused to disclose plant employment.

d
Not a producer of synthetic pulp, but processes fiber (bought from a Japanese fiber manufacturer) into a form similar to synthetic pulp (Mini Fibers 1986).

e
Plant capacity in 1985 was 30 million lbs/year.

f
Plant capacity in 1985 was 70 million lbs/year.

Sources: Textile Economics Bureau 1984, SRI International 1985, Chemical Week 1983, Ahmed 1982, Mansfield 1985, Dun's Market Identifiers 1986, ICF contact with industry 1986.

(Fibers Fabrics of Georgia 1986). Another source gave a range of tape and film thicknesses from 150-200 μm (Exxon Chemical 1986b);

- Spun-bonded fabric -- nonwoven fibrous structures produced in the form of flat fabric directly from the molten resin in one continuous process. The intermediate step of producing individual fibers (which then need to be woven into fabric) is bypassed. The individual filaments in spun-bonded fabric are continuous and have an average diameter ranging from 10-20 μm (Riegel Products 1986). Dupont's spun-bonded fabric (Tyvek®) contains filaments with diameters as small as 0.1 μm (Dupont 1986c).

- Synthetic pulp -- a relatively new class* of nonwoven fibers. Average synthetic pulp fiber diameters are 5-40 μm with maximum length of 2.5-3 mm (Rave 1985, Hercules 1986c).

- Meltblown or microfiber -- a relatively new type of polypropylene spun-bonded fiber produced by the meltblown process. Microfibers are distinct from other spun-bonded fibers in that the filaments are extremely fine and discontinuous. A mat, rather than a flat fabric, is produced from the molten resin, and the entangled fibers in the mat have lengths on the order of a few centimeters and cross-sectional diameters ranging from 0.1 to 2 μm (Porter 1981, Riegel Products 1986). One manufacturer, 3M, gave a range for the diameter of 1-5 μm, with an average of 2 μm, but stated that the microfibers in their products, Thinsulate®, were continuous (3M 1986a).

According to Fibers Fabrics of Georgia (1986), the polyolefin industry usually refers to fiber dimensions in terms of "denier" rather than μm. A denier is a weight-per-unit-length of any material, numerically equal to the weight in grams of 9,000 meters of the material. Denier is a direct numbering system in which the lower numbers represent the finer sizes and the higher numbers represent the coarser sizes. Polyolefin fibers can range from 1.5 denier to 1,000 denier depending on the intended application for the fiber.

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* Hercules is currently the only manufacture of synthetic pulp in the U.S.

(1) Continuous Fibers and Yarns

In general, polyolefin fibers are produced by one of several modifications of the melt-extrusion technique which is a two step process involving fiber formation and fiber processing. Fibers are formed by the continuous extrusion of molten polymer through a die (i.e., spinnerette), the solidification of the extrudate by heat transfer to the surrounding medium, and finally the winding of the solid extrudate onto reels. Fiber processing steps include drawing of the fiber (to as much as six times its original length) and heat treating the fiber a variety of ways to relieve thermal stresses within the fiber. Texturizing processes, which are combinations of deformations and heat treatments, may also be applied. The production of polyolefin fiber is schematically presented in Figure 1.

This process is used for the production of continuous filament yarns (or multifilament yarn), monofilament yarns, and staple fibers. The processes used are conventional spinning, drawing, and fabricating techniques commonly used in fiber manufacture.

These processes use high-speed equipment and are "fairly" automated. Operators are required at various locations on a production line to control the equipment (Crown Zellerbach 1986, Fibers Fabrics of Georgia 1986). Specific information on various job responsibilities was not obtainable. The process is enclosed for the most part, especially at the extrusion and filament formation areas, to avoid exposure to heat (Fibers Fabrics of Georgia 1986). According to Phillips Fibers (1986c) (producer of multifilament yarn and staple fibers), its "fiber line" (i.e., drawing, crimping, cutting, and conveying to baler) is an automated and continuous process. Cutting and baling operations are enclosed.

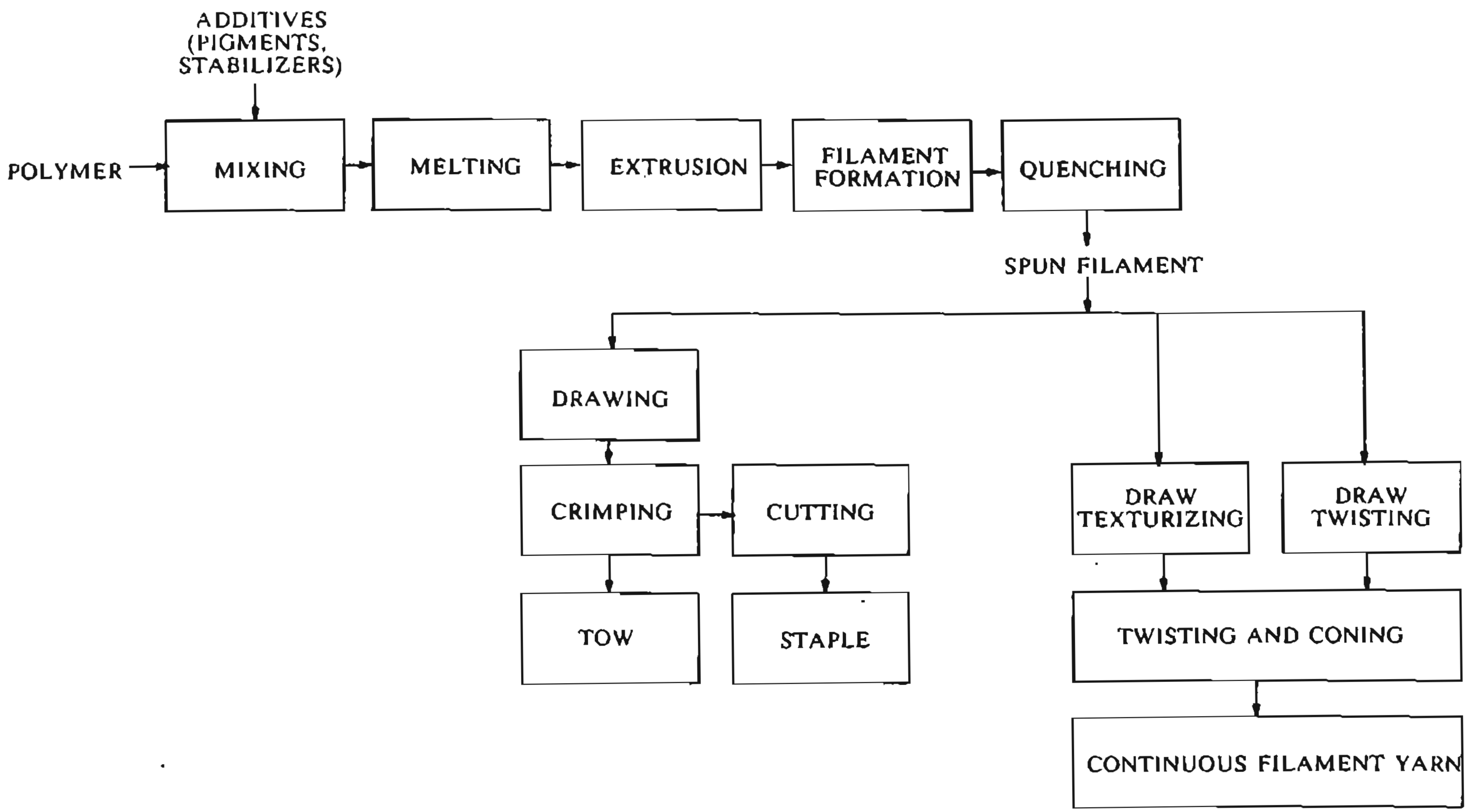

Figure 1. Process flow diagram for polyolefin fiber spinning operations.

Processes for producing other forms of polyolefin fibers such as spun-bonded fabrics, tapes and fibrillated film yarn, and synthetic pulps are quite different.

(2) Spun-Bonded Fabrics

Spun-bonded fabrics are produced directly under the spinnerette. Spun-bonding is a new process for producing textile fabric without going through the traditional carding, spinning and knitting, or weaving steps. Spun-bonded fabric is an array of continuous filaments randomly arranged into a flat sheet of uniform thickness. The filaments are "melded" to each other at cross over points, which imparts structural integrity, dimensional stability, and strength to the fabric.

The production of polypropylene spun-bonded fabrics can be generally divided into five steps (Ahmed 1982, E.I. DuPont 1986b):

- Polymer extrusion through spinnerette;
- Formation of filaments;
- Laying the filaments in random fashion in the form of a fabric;
- Bonding the filaments; and
- Finishing (e.g., heat setting, lubrication, cutting).

Figure 2 is a process flow diagram for the production of spun-bonded fabric. The first three steps are the same as in continuous filament yarn production. One manufacturer (Crown Zellerbach 1986) provided process information that confirmed the above steps. First, the polymer mixture is extruded through a spinnerette to form filaments. The filaments are drawn vertically by supplying air pressure while they are still in the molten state. The filaments are then quenched by cool air and are randomly dispersed onto a

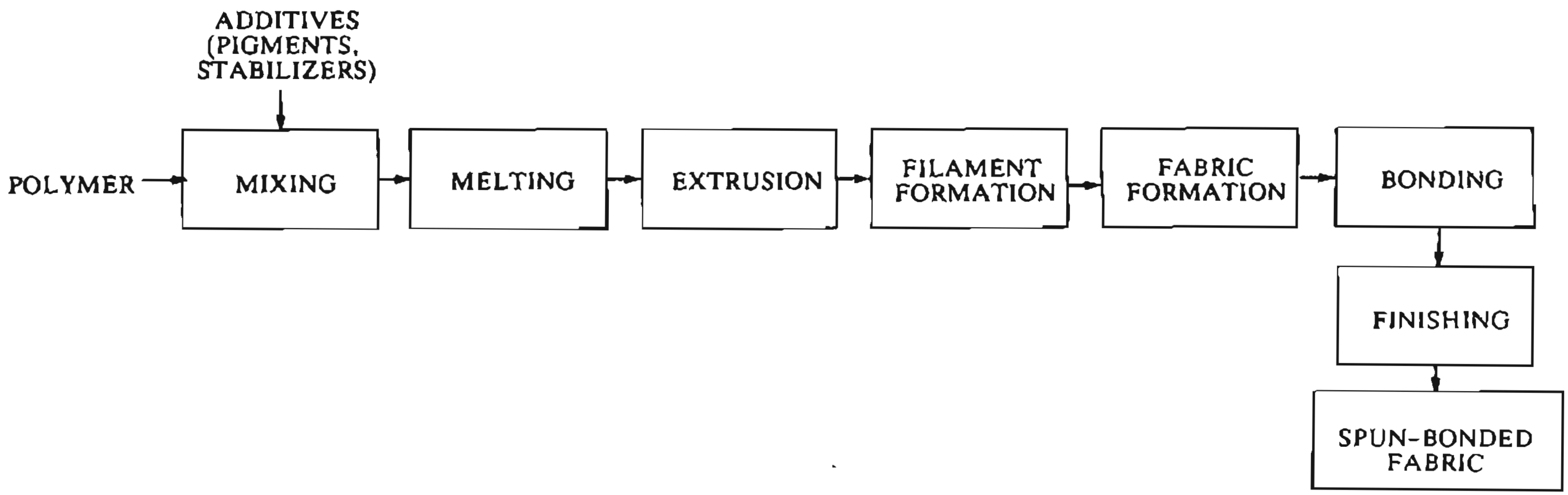

Figure 2. Spun-bonded fabric production processes.

moving wire screen to form a sheet.* The desired thickness of the sheet is controlled by the rate of motion of the wire screen. The sheet is then lifted off the screen to be bonded by passing between heated rollers. By applying heat and pressure to the sheet, the filaments are "fused" together to form fabric. The bonded sheet is then slit and wound onto rolls. Slitting is done by a laser blade or by a high pressure water jet.

A variety of treatments can be applied to the finished product to protect the fabric during secondary processing. Treatments include heat setting (to prevent the fabric from shrinking) or lubrication (to ease penetration of tufting needles into the fabric and to prevent the pierced filaments from breaking). The process is automated and only requires machine operators to control the equipment at various locations. According to DuPont (1986c), a manufacturer of spun-bonded polyolefin fiber (under the trade name Tyvek®), the filaments or fibers are generated in a closed cell and are compacted into a sheet before leaving the cell. The total fiber bundle denier formed inside the cell is 1370. DuPont stated that fibers within this bundle are interconnected. The smallest fiber cross-sectional diameter is approximately 0.1 µm. No other specific information about the process is available.

(3) Tapes and Fibrillated Film Yarn

Another polyolefin fiber class is tape and fibrillated film yarn.+ A large variety of processes are known for the manufacture of fibers from film. Three main processes for film production are currently in use

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* The filaments are typically collected in the form of a randomly laid sheet; however, they can also be collected in a uniform cross-laid fashion.

+ This fiber type is used to produce woven polypropylene industrial textiles and, therefore, is referred to as yarn.

(Ahmed 1982, Kresser 1969): (1) chill roll film casting, (2) water bath film casting, and (3) blown film production. Figure 3 provides schematics of these three processes.

Chill roll film coating and water bath film casting (Figure 3a and 3b) are based on extrusion of a sheet of film through a flat die, followed by cooling over chilled rolls or by means of a water quenching bath. Blown film production (Figure 3c) consists of extruding a ring of molten material through a die, blowing through the center of the die, and expanding the molten polymer tube so that the molten material is inflated and stretched like a balloon to the desired film thickness. The balloon is then air cooled, collapsed, and pulled away by nip rolls.

The film can be used as film yarn or it can be further processed into tape. In producing tapes, the films are drawn on heated rollers and slit into tapes of the desired width which are then wound onto spools. These processes are usually enclosed as much as possible to avoid releases of excessive heat (Fibers Fabrics of Georgia 1986).

Two manufacturers (Wayn-Tex Inc. 1986, Exxon Chemical Americas 1986a) indicated that they are using the water bath film casting method to produce films and tapes. The process is automated and requires only a few operators (less than 5) to control the machines (Exxon Chemical Americas 1986a, 1986b). Workers are required mainly at the packaging area where they remove the final product and package it in boxes (Exxon Chemical Americas 1986a, 1986b).

It should be noted that tapes and fibrillated film yarn are produced as a continuous filament (with rectangular cross-section) either as sheets (or film) or as discrete ribbons. According to Exxon Chemical Americas (1986c), there are no fibers incorporated into or associated with the production process.

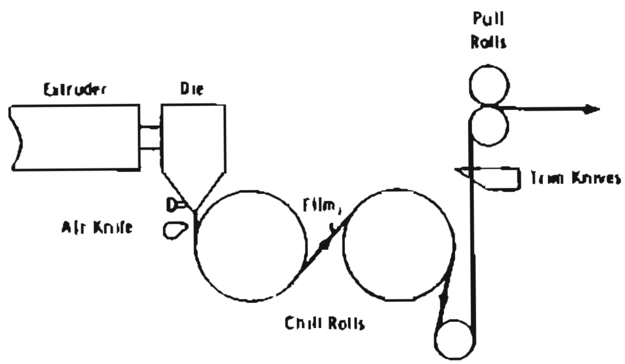

Fig. 3a. Chill Roll Film Casting

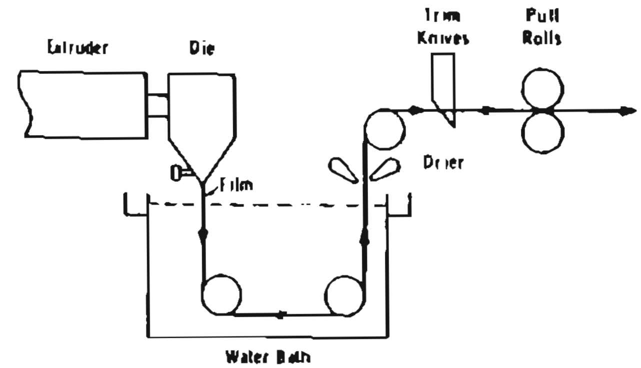

Fig. 3b. Water Bath Film Casting

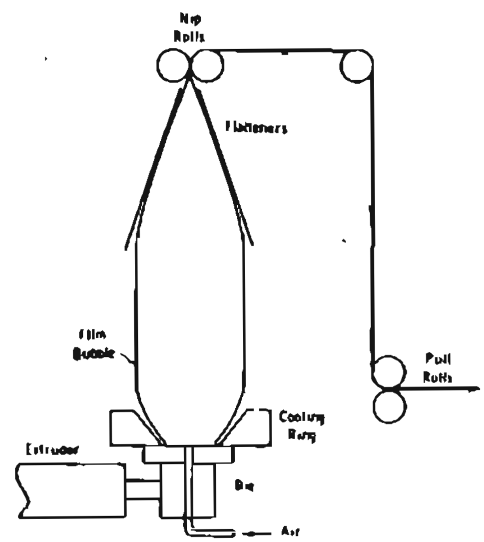

Fig. 3c. Blown Film Production

Figure 3. Fibrillated film yarn production processes.

(4) Synthetic Pulps

Synthetic pulp is produced solely by Hercules. Polyolefin synthetic pulp is highly branched, discontinuous fiber almost always made from high-density polyethylene or polypropylene.

The process used by Hercules to prepare synthetic polyolefin pulps is solution flash spinning. The process consists of passing a solution of polyolefin polymer in an organic solvent through a spinnerette. A pressure drop occurs in the spinnerette causing two liquid phases to form; one is polymer rich, and the other is polymer lean. The two-phase liquid mixture then exits through a small orifice into a chamber where the solvent is flashed off instantly, causing the fibrous product to form into pulps. The pulp fibers are cooled and conveyed into a water/wetting agent (such as polyvinyl alcohol) bath. The pulp fibers then pass through refiners or deflakers which control fiber length. The pulp is finally dewatered to form a wet sheet. Figure 4 is a schematic representation of the flash spinning process used by Hercules. Specific information about the process, the levels of automation and process enclosure, and the fiber handling procedures (once the pulp is formed) is considered proprietary information since Hercules is the sole manufacturer.

(5) Microfibers

Producers of microfibers identified in the market study by ICF (1986a) are 3M Company, Riegel Products Corporation, and Kimberly-Clark Corporation. All microfibers produced by 3M and Riegel Products are made from polypropylene.

No specific processing information was given by the microfiber producers because of its proprietary nature. In general, the process involves extruding molten polypropylene into melt-blown fibers, and these fibers are gathered

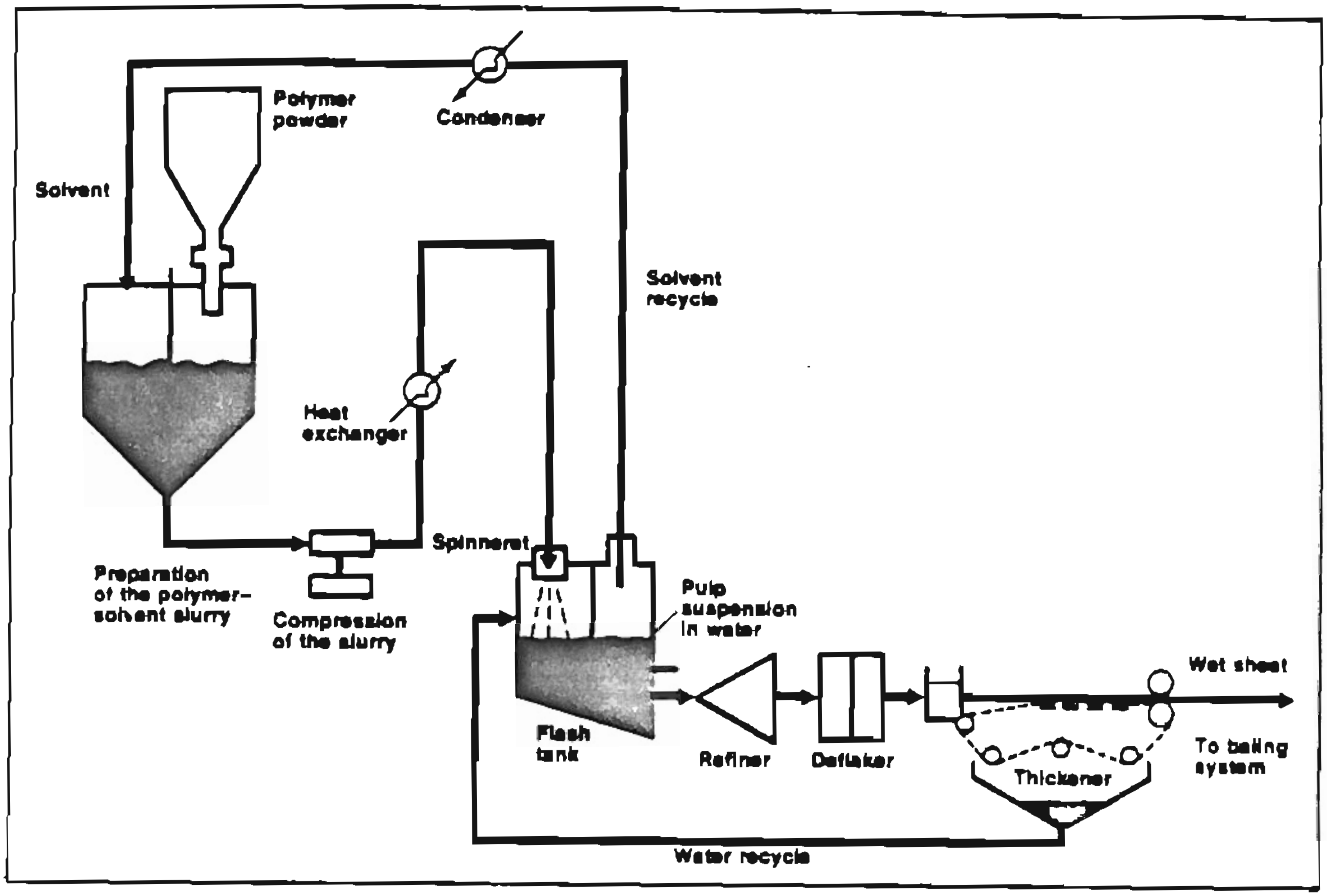

Figure 4. Synthetic pulp production -- flash spinning process.

into a nonwoven web (3M 1986b, Riegel Products 1986). Ahmed (1982) identified spray spinning and melt-blowing processes as the techniques for producing microfibers through review of the patent literature. The melt-blowing process involves feeding polyolefin resin into an extruder where the resin is melted and heated to the desire temperature for fiber formation. As the resin comes out of the extruder (or multiple die orifices), it is contacted by high-velocity hot air which attenuates the polymer into a blast of fine fibers (Ahmed 1982). Cool air is then used to quench the fibers and in turn solidifies them. The fibers are collected on a moving screen. The fibers entangle and form a cohesive web in the form of batts or nonwoven fabrics on the screen (Ahmed 1982). No bonding materials (i.e., chemical adhesives) are added during the process (3M 1986a, Riegel Products 1986). The fibers are naturally bonded (tangled up like cotton candy) because there is a lot of inter-fiber friction (or surface attraction between small fibers) that holds the fibers together (3M 1986a, Riegel Products 1986). The layer of web fibers can be further pressed lightly into a batt (or mat) form or compacted to sheets (Ahmed 1982, 3M 1986).

3M microfibers are continuous fibers and are called Thinsulate®, whereas Riegel Products fibers are noncontinuous fibers under the tradename Polyweb® (3M 1986a, Riegel Products 1986). The formation of microfibers is somewhat similar to spun-bonded fabric; however, microfibers have finer and more uniform diameters than spun-bonded fabric and lower strength (Riegel Products 1986). No other specific information about the process is available.

b. Engineering Controls and Protective Equipment

No information on engineering controls was provided by most of the fiber manufacturers contacted. Manufacturers of tapes and film yarns (Fibers Fabrics of Georgia 1986; Wayn-Tex Inc. 1986; Chase Bag Co. 1986; Exxon

Chemical Americas 1986a, 1986b) claim that the process is a "clean" process, and releases of polyolefin fibers to workplace air are unlikely; therefore, production workers at the plants are not provided with any personal protective equipment such as respirators. According to Exxon Chemical Americas (1986b), monitoring of workplace air showed no emission of fibers during the production of tape and film because the process produced a continuous sheet rather than separate fibers. Therefore, exposure to airborne fibers is not relevant for fibrillated film tapes and yarns. Manufacturers are generally more concerned about controlling exposures to carbon monoxide, noise, and other chemicals.

Fibers Fabrics of Georgia (1986) stated that during the primary processes (i.e., production of all fiber classes), releases of airborne fibers are also unlikely because filaments are rather large in size; therefore, only general ventilation systems are used. More engineering controls are available for secondary processing (e.g., weaving) than for primary processing. The cleaning workers usually wear dust masks. Phillips Fibers (1986c) stated that local ventilation is provided in all processing areas at its fiber plants. Workers wear safety glasses, safety shoes, and hearing protection in the production areas at Phillips Fibers (1986c). Hercules responded that engineering controls and protective equipment, not specifically installed to reduce airborne fiber, are used at its continuous filament and staple fiber plant in Oxford, GA (Hercules 1986d).

3. Extent of Potential Exposure

a. Number of Persons Exposed

The number of workers potentially exposed to polyolefin fibers during manufacture varies widely depending on the process used and the type of fiber produced. Large companies, such as Hercules and Amoco Fabrics, usually produce different types of fibers at the same plant (e.g., monofilament yarns and synthetic pulps are both produced by Hercules). Plant employment data are available; however, it is not currently possible to determine the number of workers directly or indirectly exposed to the fibers for each fiber class. The number of workers at a plant can range from 15 to 7,275 workers (see Table 1). Phillips Fibers Corporation (1986c) gave an overall estimate of 800 workers in its staple fiber plants (note that on Table 1, total plant employment at the three plants listed is 1,215 for Phillips Fibers Corporation). The total employment figure is an aggregate of production workers, maintenance workers, cleaning crew, and quality control workers who are all potentially exposed to airborne fibers.

In general, manufacturers feel that the number of persons directly or indirectly exposed to airborne fibers and the duration of potential exposure are confidential information (Phillips Fibers Corporation 1986a, Wayn-Tex Inc. 1986, Chase Bag Co. 1986, Wellington Synthetic Fibers 1986, Crown Zellerbach 1986). One source (Fibers Fabrics of Georgia 1986), however, provided a very general estimate that, on average, "one and a half" persons are required to operate a production line (i.e., three persons to operate two production lines). This estimate does not include workers in the packaging area. Machine repairing crews, quality controllers, and cleaning workers (who are not involved in the production process) can potentially be exposed to airborne fibers as well. Due to lack of information, the duration of exposure to airborne fibers for any worker can be assumed to be 8 hours per day, 250 days per year.

b. Respirability of Airborne Fibers

The nominal fiber sizes for all fiber classes except microfibers produced by 3M (and spun-bonded fabrics in some cases) fall outside of the respirable range (i.e., fibers less than 3.5 μm in diameter). Manufacturers have stated that since nominal polyolefin fiber sizes are fairly large, the industry is not concerned about exposure to airborne fibers. Therefore, monitoring data are generally unavailable (Wayn-Tex 1986, Exxon Chemical Americas 1986b, Phillips Fibers 1986c). Furthermore, DuPont, a producer of Tyvek® (spun-bonded fibers having some fiber diameters as low as 0.1 µm), stated that monitoring data is not available because it believes that no airborne fibers are emitted from its Tyvek® process (DuPont 1986c). DuPont claimed that its process is "very clean." The only possible point of fiber exposure identified is at the trimming step; however, this processing step is enclosed. There are no workers nearby to be exposed to airborne fibers. In addition, a vacuum device is placed near the trimming station for housekeeping purposes (DuPont 1986b).

Hercules' representative at the Oxford, GA plant commented on the potential exposure to polyolefin fibers by saying that "Exposure to such fiber particles [airborne durable fibers] does not exist because the thermoplastic material does not lend itself to particle generation. It is largely an amorphous material which is unlikely to end fracture into fiber dust" (Hercules 1986d). Hercules refused to comment on its synthetic pulp production at the LaPorte, Texas plant (Hercules 1986c). 3M (1986b) claimed that no respirable fibers have ever been detected or suspected during its manufacturing process of Thinsulate®. Due to the continuous nature of the filaments and the fact that the materials used are "not brittle enough to fracture and shed airborne particles", no emission of airborne fibers are expected (3M 1986b).

Only one source provided information on fiber exposure, indicating that airborne particulate concentrations at the fiber production plant ranged from 0.16 to 2.16 mg/m^3 (Exxon Chemical Americas 1986a). This value represents the total dust level rather than the level of airborne fibers, and is fairly low.* No fiber-like particles (fibers with aspect ratio of 3 to 1) have been noted (Exxon Chemical Americas 1986c).

In the absence of information on fiber exposure, one can conclude that there is some potential for exposure to airborne fibers at the production plant due to the nature of the work involved. A potential point of exposure is at the packaging area where workers must physically remove the wound material (e.g., changing bobbins on a filament yarn line). Also, breakage of the yarns, fibers, films, or tapes is possible during the winding operations which could cause releases of airborne fibers. The cutting step is a potential point for release of airborne fibers; however, this process is normally enclosed due to the high level of noise generated from the cutting machines (Fibers Fabrics of Georgia 1986). In addition, during the manufacture of polyolefin fibers, some scrap material is formed from interruptions in the spinning process. In the production of tape and fibrillated film yarn, scrap material can be produced in the edge trimming of tapes and films.

B. Fiber Use

There are a great number of end-product applications for polyolefin fiber. Products manufactured from synthetic pulp, microfiber, and staple fiber are of particular concern with respect to worker exposure to airborne fibers during secondary processing because of their relatively small fiber dimensions.

1. Synthetic Pulp Uses

It is believed that Hercules is the only producer of polyolefin synthetic pulp in the U.S. (Hercules 1986c, Rave 1985). Synthetic pulp was introduced to the fiber industry in the late 1970's, and the market for

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* The allowable nuisance dust level set by OSHA is 10 mg/m^3.

synthetic pulp is still developing. Polyolefin synthetic pulp comprises only a small fraction (approximately 1.5-2 percent) of the total polyolefin fiber market (Ahmed 1982). Although much development work is still underway for polyolefin synthetic pulp end-product applications, several uses are already well-established commercially including wallpaper, teabags, flooring felts, battery separator papers, thermoformed boards, specialty filters, caulks, and asphalt coatings (Hercules 1986c, Rave 1985). Due to the fact that Hercules is the sole producer of polyolefin synthetic pulp at present and that some applications of this material are still in active development, detailed information on this special class of polyolefin fiber could not be disclosed by Hercules (Hercules 1986c). Therefore, much of the discussion in this section is of a general nature.

Hercules is currently producing Pulpex® polyolefin pulps. Pulpex® are short length fibrils that resemble wood fiber and are available in two types: Pulpex P made from polypropylene, and Pulpex E made from polyethylene. Both Pulpex® products are offered in various grades in either wet or dry-fluff forms, or in wet-lap (sheet) form. The applications of Pulpex® can be roughly categorized into paper and felt products and non-paper products. Paper and felt products are categorized together because they are all made on conventional papermaking equipment. Paper products can be further divided into those that require thermal treatment (also called fusion or thermal consolidation) and those that do not require any application of heat. Table 2 lists the various applications of polyolefin synthetic pulp. Non-paper uses are mainly for asbestos replacement or for rheology control (Rave 1985).

a. Paper and Felt Products

Paper and felt products include all products manufactured by conventional papermaking equipment such as flooring felt, felt-backed vinyl

Table 2. Selected Applications of Polyolefin Synthetic Pulp

Paper[a]		Non-Paper	
Unconsolidated	Consolidated	Rheology Control	Miscellaneous
Printing and writing Paper	Teabags	Caulks, sealants[b]	Dry-laid nonwovens
Wallpaper[c]	Wet-laid nonwovens	Asphalt coatings[b]	Vinyl tile[b]
Sterilizable papers[c]	Battery separators	Joint cement	Textured paints
Flooring felts[b,c]	Automotive board	Spray cement[b]	Textured compounds
Filters[c]	Drum lids and liners	Adhesives	
Coating base stock	Labels		
	Folding boxboard		
	Corrugated boxes		
	Luggage and shoeboard		
	Embossable papers		
	Glassine, greaseproof		
	Backing sheets		
	Charts		
	Release papers		

[a] Paper applications are arbitrarily defined here as those made on fairly conventional papermaking equipment.

[b] Synthetic pulp used for asbestos replacement.

[c] Sometimes also consolidated.

Source: Rave 1985.

sheet flooring, wallpaper, teabags, battery separator papers, specialty filter products, and thermoformed boards.

The largest application of polypropylene synthetic pulp is felt backing for roll vinyl flooring (Rave 1985). Felt backing is an application for synthetic pulps which is not truly in the form of paper but is produced on paper manufacturing equipment. This felt contains polypropylene pulp (4-20 wt percent), fiberglass, cellulose, large quantities of inorganic filler, latex, and sometimes bonding resins (Rave 1985, Rave 1982). These felts are said to be similar to asbestos felt. Wallpaper, battery separator paper, and teabags are also produced using conventional papermaking equipment. Wallpaper is prepared using approximately 17-25 percent polypropylene pulp (Rave 1985). Polyolefin is good for battery separators due to its high chemical resistance and excellent dielectric properties. Tea bags are usually produced from papers containing 30 or more weighted percent of synthetic pulp (Rave 1985). In addition to these products, boards containing synthetic pulp and cellulose with a wide range of compositions are also produced using standard papermaking equipment. Boards containing synthetic pulp have an advantage over other materials in that they can be thermoformed into various shapes (e.g., automotive boards, luggage board, shoe board, furniture board, and food containers).

Information on the number of companies that use polyolefin pulp for paper applications is not available. However, Manning Paper, Manville, Lydall, Nicolet, and Owens-Corning are some of the major manufacturers of paper and felt products using fiberglass, and it is likely that they use polyolefin pulp in some of their operations.

(1) Manufacturing Process/Potential Exposure Points

The basic process for paper and felt manufacture includes: (1) introduction of fibers and various raw materials; (2) beating and refining fiber/water pulp; (3) sheet formation; (4) sheet pressing; (5) sheet drying; and (6) cutting and packaging (ICF 1986b). Paper products are typically made into a continuous sheet and are produced on high speed papermaking machines. Detailed information on the processing of paper products is presented in Chapter VII, Section B.1. Papermaking is a semi-automatic process, with raw materials being pulped in batches and then fed to a continuous papermaking machine. Rolls of finished paper are cut from the machine and are removed manually for packaging or further processing. The raw material handling operations in the beater area and the cutting and finishing operations have the potential to generate airborne fibers; local ventilation is used in these areas, personal protective equipment is not used. Eight to 10 people work on a typical papermaking line.

Paper products and boards are usually thermally consolidated. Felt backing for roll vinyl flooring, however, does not require thermal treatment. Thermal consolidation is carried out by heating the paper or board containing synthetic pulp above the polyolefin melting point (130°C for polyethylene and 165°C for polypropylene) while applying pressure (Hercules 1986c, Rave 1985). Many types of equipment can be used to thermally fuse synthetic pulps, including infrared heaters, hot-air tunnels, pull-through dryers, heated molds, heated calenders, and embossing rolls. The strength properties of papers and boards containing synthetic pulp are improved considerably by thermal consolidation (Rave 1985, Rave 1982). Synthetic pulp board properties depend heavily on the content of synthetic pulp. Synthetic pulps can be used at a low level (5-15 wt percent) to function as a binder or at higher levels (20-60 wt percent) for deep or intricate thermoforming (Rave 1985, Rave 1982).

(2) Extent of Fiber Exposure

The area with the highest potential for airborne fiber emissions during production of polyolefin pulp-containing paper and felt products is the fiber introduction area. Fiber introduction techniques are unique to each manufacturer depending on the level of sophistication of equipment available at the particular plant; the pulp introduction step can be a semi-manual operation or a fairly automated operation (ICF 1986b). Cutting of the final product is another potential fiber exposure point. Cutting, however, is an automatic operation performed on a cutting machine (ICF 1986b). The packaging step can be automated or manual. Exposure to airborne fibers is unlikely during packaging because the fibers are encapsulated within the product.

While the actual production of paper products is automated through the use of papermaking machines, machine operators are required. One source estimated that about 8 to 10 workers are needed to operate a papermaking machine (ICF 1986b). Approximately 2 to 3 workers are needed at the fiber or pulp introduction step (ICF 1986b). The duration of exposure is not known since it is difficult to predict how much time will be spent working with polyolefin pulp compared to other fiber types at a plant.

No exposure data are available to quantify the extent of worker exposures to airborne polyolefin fibers during the secondary processing of synthetic pulp to make paper and felt products. However, one can expect that airborne fiber levels are very low since the end products are comprised of only some fraction of synthetic pulp (less than 60 percent) (Hercules 1986c, Rave 1985). Polyolefin synthetic pulps are designed to be blended with wood pulp and glass fibers; therefore, there are exposures to other types of fibers as well (Hercules 1986c, Rave 1985).

According to Hercules' product literature on Pulpex®, paper and felt products are manufactured using the wet-lap form of Pulpex E and Pulpex P. The moisture content of various wet-lap grades is about 50 percent, which may greatly reduce the chance for fiber emissions. Furthermore, the nominal fiber diameters of Pulpex E and Pulpex P in wet-lap form are 10-40 μm and 20-40 μm, respectively. These fiber dimensions are not within the respirable range of less than 3.5 μm in diameter. All of the above factors suggest that exposure levels to airborne polyolefin fibers are relatively low and would be less than the exposure levels experienced during production of the polyolefin fibers themselves. According to Hercules, it has been demonstrated that both polyethylene and polypropylene in non-pulp form are practically nontoxic in animals and humans. However, it is recommended that atmospheric levels of Pulpex® be kept below 5 mg/m^3 until additional exposure and health studies are performed (Rave 1982).

b. <u>Non-Paper Products</u>

Synthetic pulps are also used in rheology control -- control of flow properties in liquids and soft solid formations (Rave 1985, Rave 1982). Synthetic pulps are used in asphalt coatings, caulks, and adhesives; these products are asbestos replacement products. The number of companies producing non-paper products using polyolefin synthetic pulp is not known.

(1) <u>Manufacturing Process</u>

The manufacturing process for non-paper polyolefin pulp products includes fiber introduction, wet mixing, and packaging steps (ICF 1986b). At the fiber introduction step, bags of fibers are manually opened by workers and are dumped into a mixer. Other solids and the liquid ingredients are added to the mixer automatically. The mixture is then blended or "wet mixed," and pumped automatically to the packaging area to be drummed. The packaging step is automated; however, an operator is required to put the lids on the drums after they are filled. The process is enclosed except for the fiber introduction and the packaging steps (ICF 1986b).

(2) Extent of Potential Exposure

Workers are potentially exposed to airborne fibers at the fiber feeding and packaging steps. Between 2 to 4 workers are required for these two operations. Exposure to airborne fibers at the packaging area is limited because the fiber is encapsulated; therefore, only the fiber feeding step is of concern with respect to fiber exposure. The bag opener and/or feeder usually wears a dust mask, coveralls, and gloves. Ventilation is also provided over the mixing vessel (ICF 1986b). In general, production of coatings and other non-paper products is not a year-round operation. The operation depends on the seasonal demand for the products. Therefore, the duration of exposure varies greatly for this industry (ICF 1986b).

Non-paper products are usually produced from the dry fluff form of synthetic pulp which is produced with fiber diameters of 6-15 μm for Pulpex E and 5-10 μm for Pulpex P (Rave 1985, Rave 1982). There is higher potential for fiber exposure from dry fluff uses than from the manufacture of products using the wet-lap form (i.e., paper and felt products). Non-paper products are produced in combination with larger and stronger fibers such as staple or glass to give desirable tensile strength, impact resistance, and flow behavior to the product (Rave 1985, Rave 1982). Therefore, workers are potentially exposed to more than one type of fiber. No exposure data for non-paper products are available.

2. Microfiber Uses

3M is the only producer of polyolefin microfibers, Thinsulate®. The main application for Thinsulate® is in thermal insulation clothing and other products (3M 1986). Type B Thinsulate® is used where a lightweight, warm, moisture resistant, and breathable insulation is required for compression resistant applications such as footwear, underwear for dry divers suits, and accessories. Type C, CS, and CDS uses including sportswear, general outerwear, gloves, window insulation, and beddings. 3M claims that Thinsulate® insulation is a new concept in thermal insulation that provides nearly twice the warmth of most competitive materials such as down and fiberfills. The application of this product is new (3M 1986). Since polyolefin microfiber comprises only a very small fraction of the industry, it was not possible to locate manufacturers of polyolefin microfiber-containing products.

a. Manufacturing Process/Potential Exposure Points

3M claims that its process is patented and it is the only producer of this type of polyolefin fiber; thus, all specific information regarding its process is considered proprietary (3M 1986). However, the conventional process for making synthetic fibers in a batting form may involve melting of the resin, spinning of the melted material into fine fibers, and settling the fibers into a bulky arrangement. The fibers may be carded to form sheets or rolls. Potential points for exposure to airborne fibers are during the spinning and carding operations. 3M sells polyolefin microfibers to other manufacturers to produce various end products (3M 1986).

Manufacturers who use polyolefin microfibers to produce end products such as quilts, comforters, and general outerwear clothing belong to the textile industry which is generally a labor intensive industry. The manufacturing process involves cutting and sewing operations to make the final products in various shapes and designs. Workers are, therefore, potentially exposed to fibers during the fabrication process. The number of workers usually employed by companies in this industry varies widely.

c. Extent of Fiber Exposure

Thinsulate® is available in various types. Thinsulate® type B, comprised of 100 percent olefin fibers (polypropylene), is produced in a batting form in rolls of 45 to 60 inches in width. The composition of Thinsulate® types C, CS, and CDS is 65 percent olefin fiber (polypropylene) and 35 percent polyester fiber (3M 1986); roll widths are also 45 to 60 inches and are available in batting form. According to a 3M representative, polyolefin microfiber diameters ranged from 1 to 5 µm with an average diameter of 2 µm. Binder is not added to these fibers during the production; these fibers are naturally bonded together due to interfiber frictions. Polyolefin microfibers are very similar to polyester fibers (3M 1986).

The basic secondary process used in producing general outerwear products (ski wear, footwear, gloves, and hats) and home application products (draperies, quilts, and comforters) is probably similar to the process used in the apparel industry which involves mainly cutting and sewing operations where operators manually operate sewing machines. These operations are often labor intensive. Workers are likely to be in direct contact with the fiber "batting" during the manufacture of quilts and comforters.

The extent of personal protective equipment, such as respirators or gloves, used by these workers is not known. In general, however, the apparel industry uses very little or no personal protective equipment. Engineering controls for this industry is also not common. Industry contacts were unable to comment on the potential for exposure to airborne fibers during secondary processing of polyolefin microfiber.

3. Staple Fiber Uses

Among the staple fiber producers in the U.S., Phillips Fibers and Hercules are the two largest producers of polyolefin staple fibers (Hercules 1986a, Phillips Fibers 1986a, ACS Industries 1986). According to one source, small producers may be phasing out the production of staple fiber due to decreasing demand (ACS Industries 1986).

Use areas for polyolefin staple fiber include: carpet face and backing, rope, home furnishings (i.e., upholstery, bedspreads, blankets), knitting yarn, fiberfill, apparel, and in geotextiles/civil engineering applications (ICF 1986a). Among these use areas, staple fibers are most commonly used in the production of rope (Ahmed 1982). Staple fibers are used in the other applications to a lesser extent -- tape and filament yarn dominate these applications (Ahmed 1982, Mould 1975). Only the production of rope is discussed in this section. The number of companies making polyolefin rope from short fibers is not known.

a. Production of Rope

Polyolefin staple fibers are designed to be processed directly on conventional rope-making machinery (Ahmed 1982). The basic rope-making process used today is similar to that used almost a half century ago; however, rope factories today are comprised of compact and fast-working machines that can deliver hundreds of feet of rope in a fairly short time (Jackson Rope Co. 1986). In addition to polyolefin staple fiber, polyolefin multifilament fiber, monofilament, and fibrillated film are also used to produce rope (Ahmed 1982). The conventional rope-making process (Fry 1977, 1982) is discussed below.

Bales of fiber are emptied into a combing machine manually. The steel teeth in the machine catch the fiber and combed it, thus straightening the fiber. The combing machine is comprised of several sets of teeth, one behind the other; each set of teeth moves faster than the one before it. As the fibers advance through the teeth, they are forced to lie parallel to each other. The fibers leaving the combing process appear as a continuous stream of soft thick untwisted fiber. The level of enclosure of the combing machine is not known.

During the combing process, the fibers are sprayed with a small amount of oil to softened them and also make the fibers easier to comb. (The oil also serves to reduced wear on the fibers when they rub against each other in the finished rope.)

The stream of fibers is then passed through a second series of combing machines which consecutively draw the fibers closer together until "slivers" are formed and are ready for spinning. The slivers are transferred to a spinning machine which separates larger slivers into smaller ones. The small slivers are moved along in streams to a place in the machine where they enter a pipe. As they leave the pipe, the slivers pass through a turning machine which twists them into yarn. The yarn is then wound onto bobbins or spools.

After the yarn is made, the next step in rope-making is the formation of strands. Strands are formed at another machine where yarns are stretched and twisted together. The strands are then further twisted to tighten them, and typically three strands are then laid about each other and twisted into a rope. The processes of forming strands and laying the rope are often combined in one machine. The finished rope is then wound and tied into coils, and is ready for sale. Figure 5 is a schematic of the steps involved in the rope-making process.

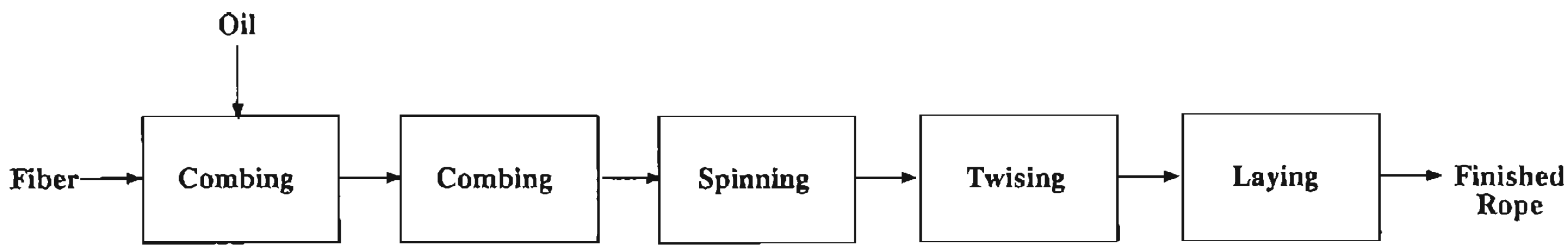

Figure 5. Conventional rope-making process.

Engineering and personal protective equipment are generally not used in this industry.

b. Potential Exposure During Rope-Making

The diameter of staple fiber ranges from 5 to 20 μm, and lengths range from 1 to 6 inches. The rope-making process is fully automated and requires very little handling of the fibers; therefore, exposure to fibers seems unlikely. The number of employees on a line and their duration of exposure are not known. However, potential points for fiber exposure are during the fiber introduction step (to the combing machine) and during the combing (or "carding") process. The handling procedures at the fiber introduction step vary among manufacturers; however, most manufacturers use some type of conveyor and an operator to handle fiber introduction (Jackson Rope Co. 1986). It is not believed that combing of polyolefin fibers would result in breaking of the fibers; even if it were, the fiber diameter would remain the same because the fiber would break horizontally not longitudinally (Exxon Chemicals 1986a).

No information on exposure levels to airborne fibers are available for rope-making using polyolefin staple fiber. Industry representatives indicated that exposures during primary processing (i.e., production of polyolefin fiber) are unlikely and, therefore, exposures to fibers during the manufacture of end products would also be unlikely (Hercules 1986b, Phillips Fibers 1986b, Exxon Chemical 1986a). No data were given to support this claim since monitoring data are generally unavailable (Wayne-Tex 1986, Hercules 1986b).

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X. WOLLASTONITE

Wollastonite is a calcium metasilicate named after William H. Wollaston, a British chemist. It occurs in coarse-bladed masses, and its particles are acicular (needle-like) in form.

A. Fiber Production

1. Fiber Producers

Commercial production of wollastonite began in the United States in the early 1950's in New York State. The world production of wollastonite in 1983 was estimated to be between 200,000 and 250,000 tons (Elevatorski 1983). The United States is the largest producer, responsible for over 60 percent of total worldwide production of wollastonite. Finland, Mexico, and India are the second, third, and fourth largest producers, respectively (ICF 1986).

Commercial production of wollastonite in the United States takes place in two states: New York and California. Table 1 presents the three companies with active mines in the U.S., and the number of employees at their facilities. NYCO Division of Processed Minerals, Inc. (hereafter referred to as NYCO) is the largest producer. NYCO produces four qualities (325 mesh, 400 mesh, 475 mesh, and 1,250 mesh) of milled grade wollastonite and two high aspect ratio (i.e., the most fiber-like) products used as fillers by the plastic industry. The four milled grade products have a maximum length of 40 μm. Based on diameters ranging from 0.1-5.2 μm, high aspect ratio wollastonite fibers may range from 0.15-78 μm in length. The wollastonite plant owned by NYCO Division employs about 130 people (NYCO 1986a).

R.T. Vanderbilt Minerals Corp. (hereafter referred to as R.T. Vanderbilt) is the second largest U.S. producer of wollastonite. Vanderbilt started this product line about nine years ago and has, since then, consistently increased its production. Vanderbilt annually produces between 30,000 and 50,000 tons

Table 1. Major U.S. Producers of Wollastonite

Company	Plant/Office	Number of Employees at this Facility
Processed Minerals Inc.	NYCO Division, Willsboro, NY	130
Vanderbilt, R.T. Company	Vanderbilt Minerals Corp. Balmat, NY/Norwalk, CT	40
Pfizer Inc.	Minerals, Pigments, and Metals Division, Victorville, CA	35

Source: Minerals Yearbook 1983, Dun's Market Identifiers 1986, NYCO 1986a.

of three qualities (W10, W20, W30) of milled grade wollastonite, which are used by the ceramics and paints industries. These products generally fall into the 200-400 mesh grade size. Vanderbilt does not produce attrition milled grade (high aspect ratio) wollastonite. Vanderbilt Mineral Corp. employs 40 people at their operations in Lewis County, New York and Norwalk, Connecticut (R.T. Vanderbilt 1986a).

Pfizer's Minerals Products and Metals Division (hereafter referred to as Pfizer) restarted production of wollastonite in 1981 after a gap of several years. Their plant in Victorville, California employs 35 people and produces mainly milled grade products. The Pfizer wollastonite mine is also in Victorville. Pfizer sells two grades of wollastonite, a 200 mesh (60 μm particles or below) and a finer 325 mesh product (40 μm or below). All of Pfizer's 15 wollastonite customers are on the west coast. Pfizer's products are sold in bulk or in 50 pound bags. These products are sold in combination with talc to produce a product which is comparable to that produced in New York by NYCO (Pfizer 1986a, Pfizer 1986b).

2. <u>Fiber Production Process/Potential Exposure Points</u>

a. <u>Mining</u>

(1) <u>Process Description and Automation</u>

NYCO mines its wollastonite approximately two miles from its mill in Willsboro, New York. In 1977, the ore was mined from open stopes (underground rooms) with regular pillars by drilling and blasting. This system has since been changed to an open pit mining method. The ore is collected with pay loaders and placed into dump trucks for transport to the mill (NYCO 1986b).

R.T. Vanderbilt uses both open pit mining and underground mining to obtain its wollastonite ore. In the open pit method, the ground is drilled and blasted, and the overburden is stripped away using earth moving equipment. A primary crusher is employed in the open pit to reduce the ore size before it is trucked approximately twelve miles to the mill. The crushed ore is shoveled into the transport trucks by loaders. In the underground method, drilling and blasting are used to loosen the ore (R.T. Vanderbilt 1986b).

Pfizer mines a small wollastonite deposit by surface mining techniques. Surface mining is similar to open pit mining; the term surface mining is used when the ore deposit has little or no overburden. The workers drill and blast the material and then load it by machine into trucks for transport to the mill. This mining process only goes on for two weeks of every other year (Pfizer 1986c).

(2) Engineering Controls and Protective Equipment

All NYCO workers are provided with safety glasses, safety shoes, and hard hats. While working in open air, Vanderbilt miners in the open pit wear dust masks to prevent breathing wollastonite fibers. In the underground mine the workers wear cartridge respirators, especially during drilling operations. All Pfizer miners are required to wear dust masks, safety glasses, safety shoes, and hard hats.

(b) Milling

(1) Process Description and Automation

The two major purposes of milling at NYCO are to separate the wollastonite from the garnet and diopside that are also found in the deposit and to reduce the ore to the desired grades of coarseness. Figure 1 is a detailed flow chart describing wollastonite milling procedures at NYCO. The ore is first dumped from the truck into a crusher pit then scraped into a pan feeder and discharged through an 18"x30" jaw crusher. An operator works the jaw crusher directing rock into the crusher and keeping the feed even. The primary discharge from the jaw crusher is screened, and the passing fraction

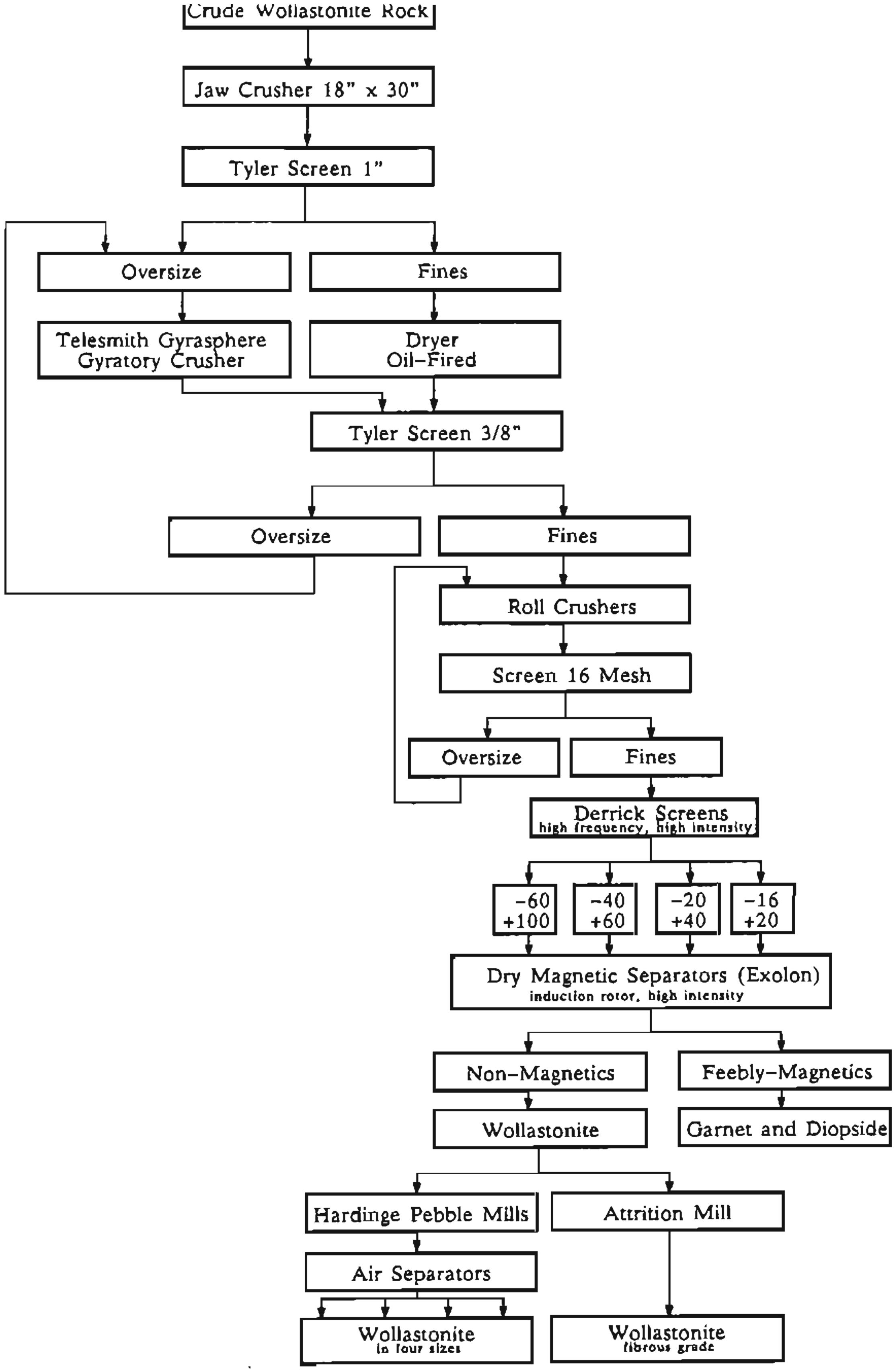

Figure 1. Flowsheet of wollastonite beneficiation process at Willsboro, NY. (Source: Andrews 1970.)

goes through a parallel flow, oil-fired dryer. The oversize fraction goes to a gyratory crusher to be broken up further. The primary and the secondary crusher discharge are in a closed circuit with the screen.

The reduced ore proceeds to two roll crushers for further reduction. Next, vibrating screens separate the product sizes. Magnetic separators draw the garnet and diopside away from the wollastonite because these impurities respond more to the magnetic field than does wollastonite. A conveyor belt takes the beneficiated wollastonite to storage tanks. Purified wollastonite is ground to four product sizes with pebble mills. The pebble mills use an air suspension system to separate the size fractions in making various grade end-products. Two fibrous products are made on an attrition mill. All products are bagged and/or shipped by bulk in trucks. This process has remained the same at NYCO for 30 years (NYCO 1986b, Zumwalde and Boeniger 1977). The bagging operations are not completely automated and are consistently a source of elevated concentrations of nuisance dust. The flotation system for particle separation by size is also a source of high dust concentrations and requires operators. We do not know if NYCO's mills and screens are enclosed.

At the R.T. Vanderbilt mill, the ore undergoes secondary crushing, drying, and vibratory screening before it is ground into its various grades in a pebble mill. Elevators take the powdered wollastonite to hoppers and then to the bagging stations for packaging. The filled bags are then placed on pallets for shipping. There is no beneficiation process here as there is at the NYCO plant because the ore contains fewer impurities. Hence there are no tailings (R.T. Vanderbilt 1986c).

At the Pfizer plant in Victorville, California only about 600 tons of wollastonite are ground per year. Pfizer's wollastonite deposit is rather small and is running out of ore. The milling process is a dry one and involves no beneficiation. No screening is necessary. The ore is broken in a jaw crusher and then ground smaller and pulverized in Raymond mills. The ground products are bagged and shipped (Pfizer 1986c).

In a Finnish plant, wollastonite goes through the following stages: drilling, blasting, loading and transport, primary crushing, manual sorting, automatic sorting, secondary crushing, fine crushing, fine milling, flotation, and bagging. The first three stages occur in the open quarry. The next four stages are done inside the mine. Fine crushing is performed in a separate building, and the remainder occurs in a flotation plant (Huuskonen et al. 1983).

As each plant, each major peice of crushing, milling, screening, and bagging equipment requires an operator.

(2) <u>Engineering Controls and Protective Equipment</u>

Shortly after NIOSH visited the NYCO plant in 1977, 17 fabric baghouse filters were installed to remove dust from the local exhaust vents near the milling, separating, and bagging machinery in the mill. This addition greatly reduced dust quantities near the magnetic separators and the bagging operations (NYCO 1986b).

An extensive ventilation system operates throughout the Vanderbilt mill. The "dustiest" area is the bagging operation which consists of two packing lines. There are local exhaust hoods over the bagging operations. As the bags are transported by conveyor belt to be palletized, the belt is vibrated to allow the exhaust systems to remove any loose dust. The pebble mills, dryers, and all conveyers and elevators for milled product transport are enclosed and exhausted to minimize respirable dust (R.T. Vanderbilt 1986b).

The Pfizer mill is equipped with a ventilation system that features dust collection vacuums. The mills are enclosed, and all of the material transport devices are enclosed and pneumatic. The packaging machinery is separated from the main part of the mill (Pfizer 1986c).

At the Finnish plant, workers on the crushing, automatic sorting, and flotation stages work in ventilated cabins and operating rooms for most of their work hours. The crusher, automatic sorters, and bagging machines all have local exhausts. Primary and secondary crushers are equipped with water sprayers to collect dust. Respiratory protection is not used (Huuskonen et al. 1983).

All NYCO workers are provided with safety glasses, safety shoes, and hard hats. It is not required that employees wear filter type dust masks, but some employees do wear them and they are available from the NYCO management upon request (NYCO 1986b).

Within the R.T. Vanderbilt mill, workers wear Ra-Cal positive pressure respirators which are equipped with filters and a full face shield made of plexiglass. A locker room is provided for the work clothes of the employees, and laundry service is provided (R.T. Vanderbilt 1986b).

All Pfizer mill workers are required to wear dust masks, as are the maintenance people. Safety glasses, safety shoes, and hard hats are also required (Pfizer 1986c).

3. <u>Extent of Potential Exposure</u>

a. <u>Number of Persons Exposed</u>

(1) <u>Mining</u>

Of the 95 hourly workers at NYCO, 10 are involved in mining operations (NYCO 1986b). The mining operations at R.T. Vanderbilt employ no more than 15 workers per day (R.T. Vanderbilt 1986b).

The Pfizer mining process requires three workers. Two workers are required to drill, blast, and load; and one trucker is required to haul the material (Pfizer 1986c).

(2) Milling

Under normal operating conditions, the NYCO wollastonite operation employs 95 hourly workers and 30 salaried employees. The salaried people are primarily support staff and office workers who have little or no contact with the wollastonite. Of the 95 hourly workers, 10 are involved in mining operations, 5 are employed in trucking the ore from the mine to the mill, 60 workers staff the mill, and 20 perform maintenance activities at the mill during the day shift. Currently, 30 of NYCO's 95 hourly workers are laid off (NYCO 1986b).

The mill that Vanderbilt uses for processing wollastonite operates for at least two shifts per day and probably three. Eleven or twelve people staff the mill (R.T. Vanderbilt 1986b). A total of ten workers are required to mill wollastonite at Pfizer during the two shifts needed for this process each month (Pfizer 1986c). At a wollastonite facility in Finland, 1-2 workers perform mining oeprations, 3-4 people load and transport the ore, and 22 people work in the mill (Huuskonen et al. 1983).

b. Duration of Exposure

(1) Mining

It may be assumed that the miners work 8 hour days and year-round at the NYCO and R.T. Vanderbilt mines. Lapses in mining activity may occur when stockpiles appear to meet upcoming demands. At Pfizer, mining is performed only two weeks every other year (Pfizer 1986c).

(2) Milling

Thy NYCO mill is run constantly, and 20 mill workers staff each of 3 shifts (NYCO 1986b). Milling is performed for two or three shifts per day, year-round at R.T. Vanderbilt's wollastonite mill (R.T. Vanderbilt 1986b). At Pfizer, the mill employs five people during each of three shifts per day. However, Pfizer's wollastonite milling operation is intermittent; milling is performed only one day per month for two shifts. This totals to less than 200 hours per year for wollastonite milling. At other times, the mill grinds other Pfizer products (Pfizer 1986c).

(3) Respirability of Airborne Fibers

The length of wollastonite fibers is about 7 to 8 times their diameter, the average diameter being 3.5 µm (ranging from 1-10 µm in diameter) (Elevatorski 1983). The length to diameter ratio (aspect ratio) depends upon the milling grade. This ratio may be as low as 3:1 or as high as 20:1. Wollastonite particles break up easily and do not have the tensile strength of glass or asbestos. Some fragments may have a 1:1 aspect ratio (NYCO 1986a). Pfizer makes wollastonite with an aspect ratio of five or six to one, while NYCO's high aspect products may have an aspect ratio of 15:1 (Pfizer 1986a).

In 1976, NIOSH performed an industrial hygiene study of the Interpace Corp. of Willsboro, New York, now known as NYCO, collecting 45 personal breathing zone samples and 15 general area air samples near processing operations in the mill (see Tables 2 and 3). Sampling and analysis procedures for wollastonite involved gravimetric sampling and phase contrast microscopy. Total and respirable mass wollastonite dust samples were collected on MSA polyvinyl chloride filters (5.0 µm pore size). Filters are weighted to the nearest 0.1 mg using a Cahn Gram electro balance. Nylon cyclones (10 mm) were

Table 2. Interpace Corporation:
Summary of Time-Weighted Average (TWA)
Airborne Concentrations of Wollastonite Fibers by Job Title

Samples by Job Title	Dust Concentrations (Wollastonite) Respirable Mass (mg/m^3)	Total Mass (mg/m^3)	Phase Contrast Microscopy 400X Magnification[a] Fibers/cc >5 um in Length	Electron Microscopy 10,000X Magnification[b] Fibers/cc >5 um in length	Fibers/cc Total fibers[c]
MINE					
0101 Driller	0.409*	0.332*	0.27	0.33	5.4
0102 Loader	--	2.714*	0.27	0.33	5.4
0103 Utility Man	--	--	0.27	0.33	5.4
MILL					
0202 Trucker Crusherman	1.346*	--	0.78	0.91	4.6
0203 Beneficiator	1.555*	--	--	--	--
0204 Beneficiator Mill-Helper	1.488*	--	20.0	11.1	33.5
0205 Miller	--	7.250*	--	--	--
0206 F-1 Miller	0.618*	2.887*	47.7	17.5	51.9
0207 Packer	1.545*	9.818*	32.0	13.1	85.4
0209 Laborer	2.120*	4.637	--	--	--
0211 Maintenance	1.822	16.092*	--	--	--
0213 Stationary General Area Samples (Milling Operations)	4.950	16.386	15.8	9.7	40.1

[a] Measures fibers ≥1 um in diameter.

[b] Measures fibers <1 um in diameter.

[c] Includes fibers <5 um in length and >3.5 um in diameter.

NOTE: (*) Represents one sample
(--) No sample collected

Source: Zumwalde and Boeniger 1977.

Table 3. Interpace Corporation: Airborne Wollastonite Fiber Size Distribution Data as Determined by Phase Contrast Microscopy

Mine and Mill Operations (Composite of Samples)	Percent of All Fibers Counted				
	Diameters	Lengths			
	≤3.5 μm	≤5 μm	≤10 μm	≤25 μm	≤50 μm
All Mine Operations	96	79	89	97	100
Beneficiating/Milling	92	27	60	91	98
Packing/Bagging	95	27	60	91	98
All Other Areas in Mill	97	27	60	91	98

NOTE: A fiber was defined as any particulate with a 3:1 length to diameter aspect ratio and with a length less than 50 μm.

Source: Zumwalde and Boeniger 1977.

used for size separation to determine respirable dust content (Zumwalde and Boeniger 1977).

To optically determine fiber size, dust samples were collected on open face AA millipore filters (0.8 μm pore size). Samples were prepared and analyzed using the NIOSH/OSHA asbestos counting method. Fibers were sized by length and diameter, and fiber concentrations were determined for fibers greater than 5.0 μm in length and expressed as fibers/cc (Zumwalde and Boeniger 1977).

Table 2 presents data on airborne dust and fiber concentrations in the Interpace Corp. mine and mill. Respirable dust concentrations for all workers monitored are below the OSHA respirable nuisance dust exposure limit (5 mg/m^3). Total dust concentrations for maintenance workers and the milling area (area sample) exceed the OSHA limit of 10 mg/m^3 and the MSHA limit of 15 mg/m^3; total dust concentrations are 16.092 mg/m^3 and 16.386 mg/m^3 for maintenance workers and the milling area, respectively. Millers and packers are also exposed to relatively high exposures of total wollastonite dust, 7.250 mg/m^3 and 9.818 mg/m^3, respectively.

Microscopic examination of fibers shows that the mill workers are exposed to higher concentrations of fibers (both those that are greater than 5 μm in length and total fibers) than the mine workers. Mine workers were exposed to less than 1 fiber/cc for fibers ≥5 μm in length and approximately 5 fibers/cc for all fibers. Mill worker's exposures range from 31.1-65.2 fibers/cc for fibers ≥5 μm in length, and from 33.5-85.4 fibers/cc for all fibers. These data indicate that milling and packaging of wollastonite generates very high levels of airborne fibers.

Phase contrast microscopy showed that 92-97 percent of the airborne fibers had a diameter of less than 3.5μm and were, therefore, respirable (see Table 3). Airborne fiber size distribution data were determined for the Interpace Corporation operations by transmission electron miscoscopy. Fibers were measured in both the mine and the mill, generating the following results (Zumwalde and Boeniger 1977):

- Diameter: 0.1 μm-5.2 μm (median 0.22 μm); and
- Length: 0.3 μm-41.0 μm (median 2.5 μm).

A significant percentage of the airborne fibers are respirable as indicated by these data.

Monitoring data were available for a plant in Finland, herein called the Finnish plant. Total dust concentrations were measured at the mine and the mill by drawing air through membrane filters and then weighing these filters. Fibers collected on millipore and nucleopore filters were examined by electron microscopy for fibers greater than 5 μm in length and less than 3 μm in diameter. Table 4 shows the concentrations of dust and fibers during the various production stages (Huuskonen et al. 1983). The figures in column one of Table 4 in parentheses indicate the number of workers at each station in the Finnish plant. The mill employs 22 workers per shift, and the mine employs 4-6 workers per shift including 3-4 loaders and transporters (Huuskonen et al. 1983).

For the last few years, the workers at the crushing, automatic sorting, and flotation stages of the Finnish milling operation have stayed within ventilated cabins and operating rooms for most of their work day (Huuskonen 1983). This is wise because total dust concentrations outside the cabins are significantly higher than dust levels inside the protective cabins. Inside control room levels range from 2 to 20 mg/m^3 (mean range 3.3-11 mg/m^3)

Table 4. Concentration of Total Wollastonite Dust and Fibers During Different Operational Stages at Finnish Plant

Operation	Concentration (mg/m^3 total dust)			Concentration of Fibers[a] (fibers/cc)					
				Optical Method			SEM		
	N	Mean	Range	N	Mean	Range	N	Mean	Range
MINING									
Drilling (1-2)[b]									
By automatic machine (outside the cabin)							5	2.6	1-5
By hand tools	6	27	11-59				5	5.8	1-21
Loading and transport (3-4)	3	0.3	0.2-0.4						
MILLING									
Primary crushing plant (1)									
Inside control room	6	3.8	2-6						
Outside control room	15	44	7-99	6	5.1	1-14	16	23	2-50
Manual sorting (13)	11	2.8	2-7				4	8.6	7-10
Automatic sorting (1)									
Inside control room	2	3.3	3-4						
Outside control room	3	67	48-84				3	6.4	4-10
Secondary crushing plant (1)									
Inside control room	2	10	10-11						
Outside control room	6	43	30-56	3	33	26-45	2	52	42-63
Fine crushing plant (1)									
Inside control room	2	11	2-20						
Outside control room	5	41	7-60	2	6.9	6-7	2	11	11-12
Flotation plant (2) (including fine milling)	6	22	15-30	5	21	8-37	4	30	15-45
Bagging (3)	2	27	25-28	2	19	15-23	3	36	27-42

[a] All fibers over 5 um in length, below 3 um in diameter, and with an aspect ratio over 3:1 were counted.

[b] The number in parentheses denotes the number of workers on the work shift.

Source: Huuskonen et al. 1983.

while outside control room levels range from 7 to 99 mg/m^3 (mean range 41-67 mg/m^3). Wollastonite dust levels outside the control rooms of primary crushing plant, automatic sorting machinery, secondary crushing plant, fine crushing plant, the flotation plant, and the bagging operation range well above American standards for total nuisance dust (10 mg/m^3 to 15 mg/m^3) (see Table 4).

Microscopic examination of the concentation of respirable fibers over 5 μm in length shows that exposures in the Finnish mine and mill are comparable to those found in the American mill discussed previously, and higher than those found in the American mine. The Finnish mine shows respirable fiber concentrations ranging from 1-21 fibers/cc with mean concentrations ranging from 2.6-5.8 fibers/cc, while fiber concentrations in the American mine were all ≤1 fiber/cc for respirable fibers ≥5 μm in length. The Finnish mill fiber concentrations range from 4-63 fibers/cc, while the American mill fiber concentrations range from 31.1-65.2 fibers/cc. The heaviest concentrations of fibers are experienced in the secondary crushing plant (average 52 fibers/cc), the flotation plant (average 30 fibers/cc), and the bagging operation (36 fibers/cc).

Table 5 is a compilation of data gathered by the Mine Safety and Health Administration (MSHA) from 1978 to 1985 which quantifies exposure to dust and quartz in the NYCO mine and mill. In the mine and on the roads and travelways, all exposure levels to total nuisance dust are below the OSHA limit of 15 mg/m^3 and the MSHA limit of 10 mg/m^3, which are both enforceable. The highest level recorded in these areas was 7.88 mg/m^3 for a cleanup man. The mill data shows that the flotation mill operators and the bagging plant operators are subject to total dust in concentrations that exceed exposure limits. Total nuisance dust concentrations experienced by the

Table 5. Mine Safety and Health Association Monitoring Results for Wollastonite Operations at NYCO

Date	Sample Location	Job	Total Dust Concentration (mg/m^3)	MSHA Exposure Limit[a] (mg/m^3)
	EXPOSURE TO NUISANCE DUST, TOTAL PARTICULATE, <1% QUARTZ (Exposure Limit: 10.00 mg/m^3)			
MINE				
11/14/78	Surface-Ore Crushing (Primary)	Dryer Operator	3.54-4.56	
04/25/79	Underground	Drill Operator	1.39	
02/13/81	Underground	Drill Operator	1.96	
11/14/78	Surface -- General	Cleanup Man	3.73	
11/15/78	Surface -- General	Cleanup Man	7.88	
02/25/81	Surface-Ore Crushing (Primary)	Flotation Mill Operator	0.75	
02/13/81	Underground -- Travelways	Front End Loader Operator	0.43-0.81	
04/25/79	Underground -- Travelways	Front End Loader Operator	1.61	
MILL				
02/26/81	Crushing	Crusher Operator	2.93	
08/13/80	Crushing	Crusher Operator	3.67	
02/26/81	Grinding	Ball, Rod, or Pebble Mill Operator	2.11	
08/13/80	Grinding	Ball, Rod, or Pebble Mill Operator	2.05	
09/12/79	Grinding	Ball, Rod, or Pebble Mill Operator	2.62	
11/15/78	Crushing	Ball, Rod, or Pebble Mill Operator	4.67	
09/02/81	Grinding	Ball, Rod, or Pebble Mill Operator	8.03	
09/02/81	Flotation and Reagent Areas	Flotation Mill Operator	14.55	
09/12/79	Flotation and Reagent Areas	Flotation Mill Operator	15.63	
09/12/79	Bagging	Bagging Plant Operator	0.71-5.21	
03/11/80	Bagging	Bagging Plant Operator	1.58-4.33	
02/25/81	Bagging	Bagging Plant Operator	3.15-5.56	
11/15/78	Bagging	Bagging Plant Operator	3.62-6.89	
11/14/78	Bagging	Bagging Plant Operator	4.03-16.76	
08/13/80	Bagging	Bagging Plant Operator	7.54-7.84	
01/22/81	Bagging	Bagging Plant Operator	10.95-11.88	
08/13/80	Bagging	Bagging Plant Operator	18.83	
12/04/80	Bagging	Bagging Plant Operator	19.02-25.91	
	EXPOSURE TO QUARTZ, TOTAL PARTICULATE, >1% QUARTZ			
MINE				
11/15/78	Underground -- Travelways	Front End Loader Operator	0.73	4.75
MILL				
03/11/80	Flotation and Reagent Areas	Flotation Mill Operator	5.70	7.32
09/12/79	Bagging	Bagging Plant Operator	0.92	5.42

[a] Exposure limit depends upon quartz concentration.

Source: MSHA 1986.

bagging operator range from 0.71 to 25.91 mg/m^3 and average at 8.6 mg/m^3. Two readings taken for flotation mill operators are 14.55 mg/m^3 and 15.63 mg/m^3, respectively. Other than these two locations, exposure concentrations are well below exposure limits.

The MSHA data was collected using gravimetric sampling methods in order to assess exposure to nuisance dust. A cyclone is not used in this method and the sample does not have the respirable fraction separated out onto a different filter.

The jobs mentioned in Tables 2, 3, and 5 are more fully described in Table 6.

B. Fiber Use

Because wollastonite is chemically inert, it is often used as a filler. The brilliant white color of pure wollastonite, along with its naturally high pH value of 9.9 (Elevatorski 1983), is responsible for its use in the coatings industry. Milled grades of wollastonite are used as pH stabilizers and brighteners in interior and exterior polyvinyl acrylic and acrylic latex coatings. Grades of wollastonite that have a high aspect ratio (ratio of length to diameter of about 20:1) are used in the plastics industry for reinforcing thermoplastics and thermoset polymer compounds.

Crushed and ground wollastonite consist of needle-shaped particles which give it high strength. It is because of the way wollastonite breaks up when milled that it is used in the production of ceramic ware to improve the mechanical properties of the final product.

Table 7 lists major U.S. producers of wollastonite, the trade name and grade of their product, and the end products that contain each brand of wollastonite. The market for attrition milled grade wollastonite is dominated by NYCO. Milled grades are used in making ceramic ware, in paints and

Table 6. Wollastonite Production -- Job Descriptions

Job Title	Duties
Driller	Drills, places explosives, and seals
Loader	Loads ore from mine into trucks, helps move ore out of mine
Utility Man	Services all mine equipment, including wiring and welding
Truck Driver	Loads and oeprates truck, transfers ore from mine to mill
Trucker Crusherman	Operates primary crusher, drying screening, and associated equipment, including cleaning and taking samples
"Beneficiator" Miller-Helper	Performs same duties as miller and beneficiator, helps operate and care for equipment
Miller	Operates all milling, separating, cleaning, takes and tests samples, performs quality control when necessary
F-1 Miller	Operates F-1 mill, cleans and takes samples, responsible for quality control for F-1 product, helps bag F-1 product
Packer	Helps bag, performs some maintenance, and assists in loading trucks and box cars
Tractor Trailer Man	Drives truck, and assists in repairs
Laborer	Assists packer, helps load trucks and box cars, miscellaneous jobs as required
Shift Breaker	Fills in for crusherman, beneficiator, miller, and packing classifications
Maintenance	Maintains mill and mine machiner, spends most of time in various locations in the mill and mine

Source: Zumwalde and Boeniger 1977.

Table 7. Grades of Wollastonite and Wollastonite-Containing Products

Name of Company	Trade Name	Grade of Wollastonite	Products Containing Wollastonite
NYCO, a division of Processed Mineral Inc., Essex County, NY	Nycor	Milled grade (200-400 mesh)	Ceramic ware, coatings, and asbestos replacement material for thermal insulation boards.
	Nyad	Attrition milled grade (high aspect ratio)	Plastic reinforcement and abrasives.
R.T. Vanderbilt Co. Lewis County, NY	Vansil W-10 W-20 W-30	Milled grade	Ceramics, paints, and plastics (as a reinforcing agent).
Pfizer Incorporated, Riverside County, California	Wolcon	Milled grade	Ceramic ware and coatings (as a pH stabilizer).

Sources: Elevatorski 1983, R.T. Vanderbilt Corp. 1986a.

coatings, and for making thermal insulation boards. Attrition milled grades (with high aspect ratio) are used by the plastic industry as reinforcing agents.

Plastics reinforcement is NYCO's second largest end-use market; NYCO's largest market is asbestos replacement materials used for thermal insulation boards, abrasives, paints, and friction paper. Approximately 400-500 companies buy wollastonite from NYCO (NYCO 1986a). Pfizer sells its wollastonite to 15 buyers (Pfizer 1986a).

The ceramics industry is the major consumer of wollastonite. It is estimated that about half of the wollastonite produced in the United States is used for making ceramics (Elevatorski 1983), whereas 25-30 percent is used to make plastic reinforcement products and thermal insulation boards (Elevatorski 1983). The paint industry is the other major consumer of wollastonite (Elevatorski 1983).

1. Ceramics

Wollastonite is used in the ceramics industry to improve the mechanical properties of ceramic ware and to reduce warping and cracking of rapidly fired ceramic materials. Wollastonite reduces thermal expansion of ceramic materials by fusing readily with silica at low temperatures. Ceramics with low thermal expansion properties do not crack as readily as those with high thermal expansion. Another cause of cracking in ceramic materials is liberation of gas during the heating process. Because wollastonite contains no water or carbonates, no gases are formed and liberated, thus reducing the risk of cracking. Another advantage of wollastonite is that it is 50 percent silica, making it an adequate substitute for free silica-bearing materials, such as sand, which are known to cause silicosis among workers in the ceramic industry.

a. Manufacturers

The American Olean Tile Co. of Lansdale, PA (hereafter referred to as American Olean) uses wollastonite in its production of ceramic tile at each of its 8 plants. Florida Tile Industries, Inc., a division of Sikes Corp. (hereafter referred to as Florida Tile), consumes wollastonite at the rate of 1,200 tons/year. Florida Tile maintains two plants, one in Lakeland, FL and one in Lawrenceburg, Kentucky. U.S. Ceramic Tile Company of East Sparta, OH purchases wollastonite from R.T. Vanderbilt for ceramic formulations. Wollastonite is quite common in these ceramic products (American Olean 1986, Florida Tile 1986, U.S. Ceramic Tile 1986).

These are the only users of wollastonite that could be identified for the ceramics industry; however, it may not be complete.

b. Manufacturing Process/Potential Exposure Points

At American Olean, bags of crushed wollastonite are opened and dumped into open top hoppers by workers. The wollastonite is mixed with other materials, including liquids, to form a soft mud. The mud contains 17-18 percent moisture, and the risk of airborne wollastonite fiber exposure greatly diminishes at this point. The soft mud is extruded into tile shapes and is allowed to dry and harden.

Employees emptying bags into the hopper wear dust masks to protect them from airborne dust. The hopper area is equipped with dust collection equipment that removes dust from the air to a bag house (American Olean 1986).

At the Florida Tile plants, wollastonite arrives in 50 lb. bags and is utilized in two ways: in the manufacture of tile glaze and in making the body of the tile (Florida Tile 1986).

In manufacturing the tile glaze, the wollastonite and other dry ingredients are first combined. This glaze mixture goes into a wet ball mill for churning with the addition of water. Florida Tile makes the body of the tile via a dry mixing technique. Wollastonite, talc, and ball clay are mixed with a very small percentage of water. In this technique, the mixture remains rather powder-like. After the body of the tile is mixed, it is pressed out into tile shapes. Next, glaze is sprayed onto the tile, and the tile is placed into a kiln so that the glaze may fuse to the tile body and harden (Florida Tile 1986).

Dust collectors are present near the tile dry mixing areas for the tile bodies and in the glaze mill room in areas where employees may contact wollastonite before water has been added. These dust collectors are among the eighteen ventilation units within the plant. There are also dust collectors on the glaze spray line and near the tile presses. Workers must operate each piece of machinery on the production line.

Employees in contact with the glaze mill, tile dry mix operations, glaze spray operations, and tile press operations all wear dust masks (Florida Tile 1986).

Most ceramics companies use the coarse 200 mesh grade wollastonite in their products, but U.S. Ceramic Tile uses R.T. Vanderbilt's finer 325 mesh grade wollastonite. Wollastonite is delivered to U.S. Ceramic Tile in hopper cars and is unloaded outside the buildings by a vacuum system into a silo. The silo feeds, via a gravity flow chute, into a weigh bottle where the amount needed for a batch of ceramics is measured. The weighed wollastonite is blown into a closed Erich mixer where it is combined with two clays, soap stone, and water. The mixture goes into a bin and a conveyer belt takes the contents of the bin to the tile presses (U.S. Ceramic Tile 1986).

The only dusty area of the plant is the unloading area, which is outside and, therefore, well ventilated. The unloading is enclosed and vacuum propelled. The mixer and bins are closed and there is little dust at the presses because seven percent moisture has been added by that point. Dust collection equipment has been installed near the batch preparation machinery and near the presses. Employees wear goggles and dust masks that are rated for silica when in heavy dust conditions. The maintenance people wear dust masks as well (U.S. Ceramic Tile 1986).

c. Extent of Potential Exposure

The dustiest operations are fiber introduction and dry mixing. Because the average diameter of unmilled wollastonite is 3.5 µm, it is likely that the majority of airborne fibers from any of the ceramic operations which use milled grades will be respirable.

At American Olean, less than six employees are involved in the ceramic tile-making process at each of the company's eight plants. Only one person per production line, the worker who charges the hopper, actually contacts the wollastonite. This is an intermittant job that is done only every fifteen or twenty minutes. At each plant there is one shift per day (American Olean 1986).

The number of employees in direct contact with wollastonite at the Florida Tile plants is seven per shift: two unload the wollastonite, two are mill operators, and three handle the dry mix operations. The press operators and the spray operators on the glaze line are in less contact with the wollastonite. Florida Tile's plants are run continually; the lines shut down for only four hours per day. Three shifts of workers staff the plants each day (Florida Tile 1986).

At U.S. Ceramic Tile, there are five employees on each shift. Three or four shifts run each day, so fifteen to twenty employees are involved with tile production each day. Five days each week there are four shifts. This facility has three production lines; two lines run seven days per week, and the other runs only five days per week (U.S. Ceramic Tile 1986). There are approximately ten maintenance people. Each puts in sixteen hours of work in the plant each week (U.S. Ceramic Tile 1986).

Hopper cars are unloaded five days per week. Batches are prepared seven days per week but not twenty-four hours per day. Car unloading and batch preparation occur only during two shifts each day.

2. Coatings

The high pH (9.9) of wollastonite makes it suitable as a pH stabilizer (replacing ammonia) in polyvinyl acrylic and acrylic latex paints. Most of the common paints contain 1/4 lb of wollastonite per gallon to maintain a desirable pH value. Wollastonite is particularly desirable as an additive in exterior paints not only because of its pH stabilizing property but also because it is chemically inert and thus imparts a weathering-resistant quality to paint that is exposed to the elements. Wollastonite's high brightness rating (a rating based on its brilliant white color) accounts for its popularity as a pH stabilizer in the coatings industry.

a. Manufacturers

The Dunn-Edwards Corp. of Los Angeles, CA uses wollastonite in one of its products, Flex-Tech, an exterior stucco coating used for bridging fine cracks in surfaces. The wollastonite serves as the material that fills in the cracks (Dunn-Edwards 1986). Sherwin-Williams buys wollastonite from NYCO and R.T. Vanderbilt for the production of ten exterior latex products. Wollastonite functions in enhancing the appearance of the paint (Sherwin-Williams 1986). At Pratt & Lambert, wollastonite is put into powder coatings for office furniture, oil filters, alternator boxes, auto window frames, wheels, mirrors, and pipe coatings (Pratt & Lambert 1986a).

A spokesman for R.T. Vanderbilt indicated that DeSoto Inc. and PPG Industries, Inc. should be added to the list of coatings industry users of wollastonite (R.T. Vanderbilt 1986d). This may not be a complete list of wollastonite users in the coatings industry.

b. Manufacturing Process/Potential Exposure Points

Dunn-Edwards uses NYCO's Nyad product, a 200 mesh grade wollastonite. The Nyad arrives at the plant in 50 pound bags on pallets. Workers slit open the bags and dump the contents into an open mixer. The wollastonite is stirred into the mill base, which is a combination of water and surfactants to which pigment is later added. Workers stack the empty bags and then dispose of them in an open trash bin (Dunn-Edwards 1986).

Over the tub of the mixer is dust collection equipment, and the worker feeding in the wollastonite is required to wear a dust mask. The maintenance people have no need of protection and wear none (Dunn-Edwards 1986).

Ground wollastonite comes to the Sherwin-Williams Company plant in 50 pound paper bags. A workman slits the bag and dumps the contents into a tank where it is wetted either by contact with water or solvent, and resin. There is no airborne dust or fibers after the wollastonite and liquid are mixed. The empty bags are collected, tied together, and disposed of in a sanitary landfill (Sherwin-Williams 1986).

Above the wollastonite feed tank, an air exhaust with fans removes dust to a collector. The workman feeding the tank wears a dust mask, helmet, and safety glasses (Sherwin-Williams 1986).

At Pratt & Lambert Inc., possible exposure to wollastonite begins as the 325 mesh fibers are weighed for a batch. The wollastonite and other dry components are combined in a dry mixer. This dry mixture feeds into a melt mixer where resins are added and the solids are completely compounded and dispersed into the liquified resin. At this point, there is no more danger of exposure to wollastonite fibers because they are all encapsulated by resin. Next, the material is flattened onto a chill roll which feeds into a grinder. The grinder breaks material into chips which are pulverized into a powder consisting of 20-30 μm average diameter particles (Pratt & Lambert 1986b).

There is vacuum dust collection at all work stations including the weigh-up area, dry mixing blenders, the hoppers that feed the melt mixer, the melt mixer, the chill roll, and the grinders. All workers wear 3M dust masks with 0.1 μm filters. The amount of particulate matter smaller than 0.1 μm in the plant is very low and approximately equal to that found in a person's home (Pratt & Lambert 1986b).

c. Extent of Potential Exposure

At Dunn-Edwards only one employee is required to perform the loading/mixing task for one shift (8 hours) each month in order to make the one batch of this paint that is made each month. The Flex-Tech product is made on only one production line, always using the same equipment (Dunn-Edwards 1986).

At Sherwin-Williams, two people are responsible for loading the mixer with wollastonite during a shift. Only about six workers come into contact with the wollastonite in the course of a day. Only one plant makes paint containing wollastonite. A couple of other plants are involved with making miscellaneous products that have some wollastonite in them. Several production lines may make wollastonite-containing products, but these products are not made continuously. A batch is made every two days. Some production lines are completely automated so that no manual loading is necessary.

At the Pratt & Lambert Cheektowaga, NY plant, ten workers and two to five supervisors and quality control people are present during each shift. The plant runs three shifts per day on both production lines (Pratt & Lambert 1986b).

The dustiest operations are fiber loading, dry mixing, and grinding (for powder coatings only). There is also potential exposure to airborne wollastonite when the paint is sanded after drying (Sherwin-Williams 1986).

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GLOSSARY

Ablative Laminate. A product made by bonding sheets of material (usually with pressure and heat) which absorb heat through a decomposition process which takes place near the surface exposed to the heat. The material is partially consumed by the heat and serves to restrict the flow of heat through the material during its use.

Acrylic Fiber. Generic name for a manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85 percent acrylonitrile units ($-CH_2CH(CN)-$) by weight.

Agglomerated. Composed of fragments of various sizes which are coupled together but are not coherent.

Aileron. A moveable part of an airplane wing or a moveable airfoil external to the wing at the trailing edge for imparting a rolling motion and thus providing lateral control.

Alkylation. The process of adding alkyl groups to another compound in making high-octane fuels.

Amide. A compound containing the $-CONH_2-$ radical.

Amorphous. Having no real or apparent crystalline form.

Aqueous. A substance made from, with, or by water.

Aramid. From aromatic polyamide; a manufactured fiber in which the fiber-forming substance is a long-chain synthetic polyamide in which at least 85 percent of the amide linkages are attached directly to two aromatic rings. (Nylon is a polyamide in which fewer than 85 percent of the amide linkages are attached directly to two aromatic rings.)

Aramid Fiber. Generic name for a distinctive class of highly aromatic polyamide fibers. Kevlar® and Nomex® are the two types of aramid fibers manufactured in the United States. Both fibers are made by DuPont.

Area Sample. An airborne fiber sample taken in the work area of an exposed worker.

Aromatic. Containing at least one benzene ring.

Aspect Ratio. The ratio of a fiber's length to its width or diameter.

Aspirator. An apparatus for producing suction, or for moving or collecting materials by suction.

Atomization. The process of dividing or fragmenting into minute particles or into a fine spray.

Attenuate. To make thin and slender as in the formation of fiber from molten glass.

Attrition Mill. A grinding apparatus that preserves the length of wollastonite fibers.

Axial. Situated around, in the direction of, on, or along an axis.

Baghouse. A dust collection device that removes dust from the workplace and traps it away from the worker's environment.

Batt. Layers or sheets of raw cotton or wool, or of synthetic fibrous material used for lining quilts; also, a blanket of thermal insulation.

Beneficiation. To treat a raw material so as to improve its properties (e.g., remove impurities).

Binder. A thermosetting resin used to treat fibrous products during production so that fibers will adhere to one another.

Blowing Wool. A loose fiber insulation product manufactured from fiberglass or mineral wool which is blown through a hose towards the area of application; generally used for attic and crawl space insulation.

Bonded Mat. Board manufactured using a modified textile process.

Bushing. A container used for melting and feeding glass in the forming of individual fibers or filaments. The container is electrically heated and made of alloy encased in insulating material. Also refers to the outer ring of a circular tubing or pipe die which forms the outer surface of the extruded tube or pipe.

Calender. To press between rollers or plates to produce sheets of desired thickness and smoothness.

Carbon Fiber. Carbon fibers have moderate tensile strength and are produced mainly from polyacrylonitrile (PAN). The composition of carbon fiber is very similar to graphite fibers; the major difference between carbon and graphite fibers is in the tensile strength of the fibers (see graphite fiber).

Carbonization (pyrolysis). The process of heating in an inert atmosphere to temperatures ranging from 1000-1500°C to change the chemical composition of a material. All non-carbon elements are driven off.

Carding. See Combing.

Catalyst. A substance that initiates a chemical reaction and enables it to proceed under different conditions than otherwise possible, but which is not consumed in the reaction.

Cellulose. A natural carbohydrate high polymer (polysaccharide). Cotton fibers are almost pure cellulose; wood contains about 50 percent cellulose.

Centrifuge. A machine which uses centripetal force to separate substances of different densities.

Ceramic Fiber. Ceramic fibers are fibers made of aluminum silicate or other ceramic materials.

Chopped Strand. Chopped textile fiberglass used as a reinforcement material.

Cold End. Fabrication/finishing end of fiber production line.

Combing. A process by which fibers are oriented parallel to one another by running a metal or plastic strip with teeth through a mass of fibers.

Combustion. The process of burning or oxidizing, accompanied by the emission of light and heat.

Composite. A homogeneous material made from several materials to obtain specific characteristics and properties. Composite classes are based on the form of the constituents: Laminar -- composed of layered or laminar constituents; Fibrous -- having a dispersed phase of fibers; Flake -- having a dispersed phase of flat flakes; Particulate -- having a dispersed phase of small particles; Skeletal -- composed of a continuous skeletal matrix filled by a second material.

Creel. A mechanism for holding the required number of roving spools or supply packages in the necessary position for unwinding onto the next processing step.

Crystalline. Composed of crystals.

Cupola. A vertical cylindrical furnace for melting of blast furnace slag. Near the bottom of the cupola is a tapping spout for discharging of the molten material.

Curing. (a) The process by which resins or plastics are set in or on the materials by heat treatment. (b) Fixation of a thermosetting binder by heat in an oven.

Denier. A weight-per-unit-length measure of any linear material. It is the weight in grams of 9,000 meters of the material. The denier system is used for numbering filament yarns, man-made staple, and tow. Denier is a direct numbering system in which the lower numbers represent the finer sizes, and higher numbers the coarser sizes.

Dielectric. A material which permits the passage of lines of force of an electrostatic field, but does not conduct the current.

Dimension Stone. Stone cut to specified size for use as a building material.

Disperse. To break up randomly; to evenly distribute particles throughout a medium.

Dragline. An excavating machine in which the bucket is attached by cables and operates by being drawn toward the machine.

Drawing. The process of stretching the yarn to introduce molecular orientation to obtain a stronger fiber.

Drilling Mud. A soft material used by drillers of the earth's crust to suspend and remove material loosened by the drill bit.

Durable Fibers. Fibers which are non-biodegradable and can survive in biological systems for long period of time.

Electrical Conductivity. The quality or ability to transmit electricity. The electrical conductivity is the reciprocal of electrical resistivity.

Electron Microscopy (EM). A method of measuring fibers less than 1 μm in diameter.

Erionite. A member of the naturally occurring group of hydrous silicate mineral fibers called zeolites.

Fabrication. The process of producing plastic products from molded parts, rods, tubes, sheeting, extrusions, or other form by operations such as cutting, drilling, punching, grinding, and tapping. Fabrication includes the joining of parts together or to other parts by mechanical devices, adhesives, heat sealing, or other means.

Fiber. A fundamental form of solid (usually crystalline) characterized by relatively high tenacity and a ratio of length to diameter (aspect ratio) of greater than or equal to three to one as specified by OSHA for regulatory purposes. Natural fibers come from animals (e.g., wool and silk made of protein), vegetables (e.g., cotton made of cellulose), and minerals (e.g., asbestos). Cotton fiber is called staple and rarely exceeds 2 inches in length.

Fiberglass®. A variety of products made of or with glass fibers or glass flakes including insulating wools, mats and rovings, coarse fibers, acoustical products, yarns, electrical insulation, and reinforced plastics.

Fiberglass Wool. Short filaments of glass fiber which are primarily used in insulation products.

Fibrid. A microscopic fibrous material.

Fibril. Fibrils are fine threadlike material into which a fiber can be longitudinally split.

Fibrous Glass. A manufactured fiber in which the fiber-forming substance is glass. Glasses are a class of materials made from mixtures of silicon dioxide or oxides of various metals and other elements that solidify from the molten state without crystallization. Fibrous glass fibers will break perpendicular to the length of the fiber but not longitudinally into thinner fibers.

Filament. A filament is a continuous fiber usually made by extrusion through a spinneret (e.g., nylon, glass, polyethylene). In the textile field, many filaments are often twisted together to form yarn.

Fine Fibers. Glass fibers with a nominal diameter on the order of 1 μm.

Flame Attenuation (FA) Process. A process for making fiberglass wool which involves passing the molten glass in front of a flame jet. The glass is attenuated by the flame jet.

Floc. A fluffy mass formed by the aggregation of a number of fine suspended particles.

Fluffing. To make soft or airy.

Fluid Bed. A bed of granular material through which gases are blown at a rate sufficiently high to cause the bed to expand and act as a fluid.

Fly. The chaff that may separate from fiber during handling; longitudinal fracturing.

Fourdrinier Machine. A machine used to make paper continuously.

Gellant. A material used to cause gelling.

Graphite Fiber. Graphite is a crystalline form of carbon. Graphite fibers have high tensile strength (50,000 to 150,000 psi) and are made from rayon or polyacrylonitrile. Polyacrylonitrile precursor fibers are processed through a series of ovens in which the fibers undergo a number of complex chemical reactions (including carbonization) to produce carbon and graphite fibers (see carbon fibers).

Graphitization. The process of pyrolyzation in an inert atmosphere at temperatures greater than 1800°C, usually as high as 2700°C, to produce a turbostratic "graphite" crystal structure.

Hammer Mill. A grinder or crusher in which materials are broken up by hammers.

Hopper Car. A railway freight car with a floor sloping to a hinged door for unloading bulk materials.

Hot End. Furnace end of fiber production line.

Hydrocracking. Breaking up long hydrocarbon chains into smaller components.

Impact Crusher. Device for reducing large pieces of ore to small ones for finer milling.

Inert. A material which does not chemically react with the other components in the system.

Inorganic/Synthetic Fiber. Fibers which include fibrous glass, mineral wool, ceramic fiber, and carbon/graphite fibers.

Ion Exchange. A reversible interchange of one kind of ion present on an insoluble solid with another of like charge present in the solution surrounding the solid. The reaction is especially used for softening water, the purification of chemicals, or the separation of substances.

Isotope. Any of two or more species of atoms of a chemical element with the same atomic number and position in the periodic table and nearly identical chemical behavior but with differing atomic mass or mass number and different physical properties.

Kaolin. A fine clay used in ceramics and refractories.

Kaowool®. Tradename for a stable, high-temperature alumina-silica ceramic fiber. Kaowool® can be used up to 2300°F; its melting point is 3200°F. The diameter of the fibers is 2.8 microns, and the length of the fibers can be as high as 10 inches. Kaowool® is used as an insulating material.

Kevlar®. Trademark for an aromatic polyamide fiber (terephtholamide, poly-1, 4-phenylene) of extremely high tensile strength and greater resistance to elongation than steel. Kevlar® is used as a reinforcing material for plastic composites.

Kiln. An oven, furnace, or heated enclosure used for processing a substance by burning, firing, or drying.

Magazine. A supply chamber. Holds items to be fed into a machine.

Mandrel. The core around which paper-, fabric-, or resin-impregnated glass is wound to form pipes, tubes, or vessels. In extrusion, the central finger of a pipe or tubing die.

Matrix. A resin. In reinforced plastics, the material used to bind together the reinforcing material.

Mesh Grade. A particle size measurement; the number of the mesh grade refers to the number of openings that are present in a linear inch of screen used to select the particles.

Mesophase. A stage of liquid-crystalline transformation which a material reaches when heated under appropriate conditions.

Microfibers. Fibers with a nominal diameter less than 1 μm.

Micronize. Pulverize into particles having diameters of a few microns.

Modulus of Elasticity -- Ratio of stress (or applied load) to strain (or deformation) produced in a material that is elastically deformed; a measure of elasticity.

Molecular Sieve. Crystalline material that selectively adsorbs molecules of gasses and liquids.

Nominal Diameter. The manufacturer's reference diameter for their fiber product. The actual diameter of the fibers is generally distributed above and below the nominal diameter.

Nuisance Particulates (Dusts). Dusts with a long history of little adverse effect on lungs and which do not produce significant organic disease or toxic effect when exposures are kept under reasonable control. Nuisance dusts include but are not limited to alumina, calcium silicate, cellulose, graphite, mineral wool fiber, silicon, and silicon carbide.

Nylon. Generic name for a family of polyamide polymers characterized by the presence of an amide group (-CONH). Nylon fibers are crystalline, thermosplastic polymers.

Olefin Fibers. A manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85 percent of ethylene, propylene, or other olefin units by weight.

Optical Microscopy (OM). A method of measuring fibers greater than 1 μm in diameter.

Organic/Synthetic Fiber. Fibers which include aramid fibers, polyethylene pulp, and polypropylene pulp and fibers.

Orifice. An opening through which a substance passes.

Overburden. Material overlying a deposit of useful geological materials or bedrock.

Oxidation. The process of changing the nature of fiber by adding oxygen to the basic structure.

PAN. Polyacrylonitrile fiber, a polymer of acrylonitrile.

Personal Sample. An airborne fiber sample taken in the breathing zone of an exposed worker.

Phase Contrast Microscopy. A microscope that translates light phase differences transmitted through or reflected by the object into differences of intensity in the image.

Pitch. Coal tar or petroleum residue. Pitch is one of three possible precursors used to make carbon fibers.

Plying. A textile process used to manufacture yarn by twisting continuous strands of fiber together.

Pneumatic. Moved or worked by air pressure.

Polyamide. a high molecular weight polymer in which amide (-CONH-) linkages occur all along the chain.

Polyester. Generic name for a manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85 percent of an ester of a dihydric alcohol and terephthalic acid by weight. The structure in most polyester fiber is polyethylene terephthalate. Fiber size varies from 1 to 1000 microns in length and 1 to 40 microns in diameter.

Polyethylene Pulp. A very fine, highly branched, discontinuous, water-dispersible fiber. This pulp has an irregular surface with crevices which appear film-like. Average lengths of pulp fibers are one millimeter, with a maximum length of 2.5 to 3 millimeters. Pulp diameters range from 5 to 40 microns.

Polymerization. A chemical reaction in which two or more small molecules combine to form larger molecules that contain repeating structural units of the original molecule.

Polypropylene Pulp and Fibers. Synthetic pulp with an irregular surface containing numerous crevices and having a bright, film-like appearance. Staple fibers of polypropylene are smooth rods of solid polymer; average lengths are generally one millimeter with a maximum length of 2.5 to 3 millimeters, diameters are 5 to 40 microns.

Pozzuolanic Cements and Concretes. Finely divided siliceous, or siliceous and aluminous material that reacts chemically with flaked lime at ordinary temperatures in the presence of moisture to form slow-hardening cement.

Pre-Preg. Fiber pre-impregnated with a matrix. Ready-to-mold material in sheet form and stored for use.

Processed Mineral Fiber. Fibers produced from blast furnace slag and silicates often referred to as rock or slag wool.

Pugmill. A machine in which materials (like clay and water) are mixed, blended, or kneaded to a desired consistency.

Pulp. The material used in making paper and cellulose products prepared from various materials, such as rags but mainly wood, by chemical and mechanical means.

Pyrolysis. Chemical change brought about by heating in an inert environment.

Quench. To cool suddenly by plunging into water, oil, or the like.

Raymond Mill. A machine used to grind ores to very fine mesh sizes.

Rayon. Any group of smooth textile fibers made in filament and staple form from cellulose material by extrusion through minute holes.

Reconditioning. Reclamation and processing of scrap for reuse.

Refractory. Difficult to fuse, corrode or draw out, capable of enduring high temperature.

Resiliency. The ability of a strained body to recover its size and shape after deformation, caused especially by compressive stress.

Respirable Fibers. Fibers with diameters less than 3.5 microns which can enter the small airways of the lower respiratory tract.

Rheology. the study of the change in form and the flow of matter, embracing elasticity, viscosity, and plasticity.

Ripper. Machine used to break up solid rock or ore.

Roller Mill. A machine that crushes and grinds ores by forcing them between two rotating cylinders.

Rotary Spin (RS) Process. A process for making fiberglass wool which involves spinning the molten glass from a perforated rotor. The glass flows through the perforations and is attenuated (broken off in short lengths) by centripetal force.

Shot. Impurities in unprocessed bulk fiber.

Sinter. To cause to become a coherent mass by heating without melting.

Size. A treatment consisting of starch, gelatin, oil, wax, or other substance that is applied to fibers at formation to protect the surface and aid in the process of handling and fabrication, or to control the fiber characteristics. The treatment contains ingredients that provide surface lubricity and binding action, but has no coupling agent as a finish does. Prior to final fabrication, the size is removed by heat-cleaning, and a finish is applied.

Sluiceable Demineralization Equipment. Vessels that are loaded and unloaded by water carrying suspended materials that remove specific ions from solution.

Sluicing. To wash with a stream flowing through a floodgate.

Slurry. A watery mixture of insoluble matter such as mud, lime, or plaster of paris.

Spinneret. A small metal plate, thimble, or cap with fine holes through which a chemical solution is forced in the spinning of man-made filaments.

Staple Fiber. Fibers of spinnable length manufactured directly or by cutting continuous filaments to short lengths (usually 1/2 to 2 inches long ; 1 to 5 denier).

Stope. A steplike excavation formed by the removal of ore from around a mine shaft.

Stripping. A mining technique in which ore is removed from the earth's surface after removing overburden, rather than using tunnels to gain access to the ore. Strip mining.

Super Micron Mill. A machine that mills material to micron size particles.

Surfactant. A surface active substance often functioning as a detergent. A substance which reduces tension at a material's surface.

Tensile Strength. The maximum tensile load per unit area of original cross section sustained by a specimen during a tension test. It is expressed in psi. The tensile load is the maximum load sustained by the specimen during the test whether or not this is the same as the tensile load at the moment of rupture.

Textile Fiberglass. Continuous filaments of glass fiber which are generally woven into fabric products, or are chopped for use in reinforced plastic products.

Thermal conductivity. The quality or property of transmitting heat.

Thermoplastic. Capable of softening when heated and hardening again when cooled.

Thermoset. Capable of becoming permanently rigid when heated or cured.

Thixotropic. Having the property of various gells of becoming fluid when disturbed.

Tow. A loose, basically untwisted strand of synthetic fiber.

Tuff. A rock composed of the finer kinds of volcanic debris fused together by heat.

Viscous. Describing the property of resistance to flow exhibited within the body of a material, expressed in terms of relationship between applied shearing stress and resulting rate of strain in shear.

White Fiber. A fiber which has not been coated with a sizing material.

Wollastonite. Wollastonite is a natural fibrous calcium silicate ($CaSiO_3$) found in metamorphic rocks. Wollastonite is used in ceramics and as a substitute for asbestos in wallboard and brake linings.

Young's Modulus. The ratio of tensile stress to tensile strain below the proportional limit.

Zeolite. A hydrous silicate analogous in composition to the feldspars. Acts as ion-exchanger and is used in water softening and as adsorbents and catalysts.

cc = cm^3 = cubic centimeter.

μm = micrometer = micron.

mg/m^3 = milligram per cubic meter.